NOTE

This Microfiche meets the quality requirements of the American National Standard for Microfiche of Documents (ANSI PH5.9-1975). However, because of imperfections in the document from which it was made, it contains images that are illegible or difficult to read. The source document for this microfiche is the best copy that could be obtained prior to filming.

CIS Congressional Information Service
Washington, D.C.

101th Congress
1st Session

COMMITTEE PRINT

S. Prt.
101-61

REFORM AND INNOVATION OF SCIENCE AND EDUCATION: PLANNING FOR THE 1990 FARM BILL

COMMITTEE ON AGRICULTURE, NUTRITION, AND FORESTRY UNITED STATES SENATE

DECEMBER 1989

Printed for the use of the
Committee on Agriculture, Nutrition, and Forestry

U.S. GOVERNMENT PRINTING OFFICE

22-829 ⇆ WASHINGTON : 1989

S162-3

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, DC 20402

COMMITTEE ON AGRICULTURE, NUTRITION, AND FORESTRY

PATRICK J. LEAHY, Vermont, *Chairman*

DAVID H. PRYOR, Arkansas	RICHARD G. LUGAR, Indiana
DAVID L. BOREN, Oklahoma	ROBERT DOLE, Kansas
HOWELL HEFLIN, Alabama	JESSE HELMS, North Carolina
TOM HARKIN, Iowa	THAD COCHRAN, Mississippi
KENT CONRAD, North Dakota	RUDY BOSCHWITZ, Minnesota
WYCHE FOWLER, Jr., Georgia	MITCH McCONNELL, Kentucky
THOMAS A. DASCHLE, South Dakota	CHRISTOPHER S. "KIT" BOND, Missouri
MAX BAUCUS, Montana	PETE WILSON, California
J. ROBERT KERREY, Nebraska	SLADE GORTON, Washington

CHARLES RIEMENSCHNEIDER, *Staff Director*
JAMES M. CUBIE, *Chief Counsel*
CHRISTINE SARCONE, *Chief Clerk*
CHARLES CONNER, *Staff Director for the Minority*

FOREWORD

The papers included in this document put forth important ideas and proposals for reform of our agricultural science and education programs. While the authors represent a wide array of perspectives, they together call for increased investment in sustainable agriculture, a greater focus on biotechnology, and overall structural reform.

This committee print will be reviewed by the members of the Senate Committee on Agriculture, Nutrition, and Forestry as we prepare for the 1990 farm bill. Policymakers, university researchers, Extension Service leaders, rural advocates, environmentalists, and all those involved in agricultural science and education programs should make this document essential reading.

PATRICK J. LEAHY,
Chairman, Committee on Agriculture, Nutrition, and Forestry.

CONTENTS

Page

Foreword III

SUSTAINABILITY

Sustainability, a Goal for American Agriculture: Overview and Summary by Garth Youngberg and Charles A. Francis 1

Sustainability: Research and Extension

Agricultural Sustainability Research Needs and Progress by Robert Rodale 13
The Importance of Biological Control in Agriculture: An Underused and Renewable Natural Resource by Marjorie A. Hoy 19
The Integrated Pest Management Experience by George W. Bird 31
The LISA Program and the Role of the Land-Grant Universities by Brian F. Chabot 43

Sustainability: Driving Forces

Consumer Demand for Sustainable Agriculture by Michael Jacobson and Dan Howell 53
Diversity in Crop Production by David F. Bezdicek 59
International Forces for Agricultural Sustainability and Their Influence on U.S. Agriculture by Richard R. Harwood 67

BIOTECHNOLOGY

Agricultural Biotechnology—An Overview of Issues Facing Policymakers by Robert B. Nicholas 75

Biotechnology: Opportunities

An Overview of the Biopesticides Industry by Jerry Caulder 87
Products in Biotechnology by Richard D. Godown 95
Implications of Plant Genome Mapping by Wm. Hugh Bollinger and Dale J. Hansen 103

Biotechnology: Risk Assessment Research

Integrating Biotechnology Into Agricultural Systems: The Need for More Experimental Agriculture at the Farm Level by Fred Gould 117
Ecological Considerations and Recommendations by the Ecological Society of America 125

Biotechnology: Regulation

USDA's Oversight of Biotechnology by Rebecca J. Goldburg 137
Agricultural Biotechnology Oversight: Capability or Calamity? by Edward L. Korwek 149

Biotechnology: At the Farmgate

Biotechnology at the Farmgate: Opportunities for Farmers by A. Ann Sorensen 157
Sustainable Agriculture and the Other Kind of Biotechnology by Jack Doyle 169

STRUCTURAL REFORM

	Page
Overview on the Need for Structural Reform in Agricultural Research by Dr. William E. Marshall	181
Reinvestment in Food, Agriculture, and Environment Research Capability: Need for a National Initiative by Charles M. Benbrook	187
Competitive Versus Formula Funding: Assessing the Risks and Benefits by Donald L. McLean and Catherine W. Donnelly	193
Changes Necessary for the United States to Compete in an Expanding Global Agricultural Economy by William R. Furtick	197
Agricultural Research as Social Planning: Setting Agricultural Research Priorities to Advance Social Goals by Chuck Hassebrook	207
National Peer Review of Federal and University Agricultural Research Facilities by Jack Marvel	215
Higher Education Needs in Agriculture by Roger Mitchell	223
An Agenda for the 1890 Colleges and Universities by Ocleris Simpson	229
Federal Support of Adaptive Agricultural Research and Extension by Donald Holt	235
Conducting and Implementing Research in Production Agriculture; a University Bench Scientists' View by Marvin K. Harris and Philip J. Hamman	247

SUSTAINABILITY

SUSTAINABILITY, A GOAL FOR AMERICAN AGRICULTURE: OVERVIEW AND SUMMARY

(By Garth Youngberg, Institute for Alternative Agriculture, Greenbelt, MD and Charles A. Francis, Professor of Agronomy, University of Nebraska at Lincoln and Extension Crops Specialist)

The phrase "sustainable agriculture" is widely used today to describe an ideal future agricultural system for the United States and the world as a whole. When the word is used in its everyday sense, a sustainable system is understood to be one that can be maintained indefinitely. In agriculture, the term has come into use because of the perception that many conventional farming practices are destructive to our soils, water, and other essential elements upon which the entire food system, and the community at large depends. Some of the same practices also depend on heavy investment of non-renewable fossil fuels.

A few specifics are needed to support the above generalizations. Research has clearly documented the link between clean tillage/continuous monocropping and both soil erosion and nutrient depletion, for example. It has also linked excessive use, even at recommended rates, of fertilizers and pesticides with water contamination. Heavy use of fossil fuel-based production inputs contributes to the economic pressures on many farmers. Concentrated livestock operations are often associated with water contamination from cattle manures. And, although research is less conclusive in this area, many consumers associate the excessive use of certain pesticides with reduced food safety and with increases in related health risks.

Because of the pervasive nature of these problems and growing public concern about environmental and health risks from conventional agricultural practices, it is highly likely that pressure to use more low-input technologies and to make agriculture more sustainable will continue to grow in the decade to come. For these reasons, the Institute for Alternative Agriculture has proposed that the goal of sustainability be adopted as an overall goal for the 1990 farm bill. This stance is supported in principle by a growing number of farmers, ranchers, researchers, extension specialists, and public interest organizations.

Sustainable Agriculture as a Goal

It is important, in this context, to recognize the difference between the goal of sustainable agriculture and the methods that are used to achieve the goal. The concept of sustainability itself has been described by scientists meeting at the 1988 annual convention of the American Society of Agronomy. According to these participants, a sustainable agriculture is one "that, over the long term:

(1) enhances environmental quality and the resource base on which agriculture depends, (2) provides for basic human food and fiber needs, (3) is economically viable, and (4) enhances the quality of life for farmers and society as a whole." This clearly focuses on the identification of goals, rather than on particular methods to reach them.

A broader definition was developed by Francis and Youngberg in their introductory chapter to the book, "Sustainable Agriculture for Temperate Zones" (Francis et al., 1989):

"Sustainable agriculture is a philosophy based on human goals and on understanding the long-term impact of our activities on the environment and on other species. Use of this philosophy guides our application of prior experience and the latest scientific advances to create integrated, resource-conserving, equitable farming systems. These systems reduce environmental degradation, maintain agricultural productivity, promote economic viability in both the long and short term, and maintain stable rural communities and the quality of life."

Use of the goal of sustainability as a focal point for the 1990 farm bill would call for evaluation not only of research and education efforts funded by this bill, but also of commodity programs and other provisions as well. These programs all have an impact, both short and long term, on agricultural sustainability. For example, it is now widely known that the "base acreage" provisions of current farm commodity programs discourage crop rotations and enterprise diversity. Such provisions create very real obstacles to the use of legume-based cropping systems, an approach known to improve soil and help reduce crop pests, and constitute a hindrance to expanded cultivation of non-program crops.

Much research evidence supports the use of particular methods that produce healthier soils, make more efficient use of nutrients, and conserve water, while also providing economic returns that make "low-input" systems competitive with "conventional" ones. Consider, for example, research that shows long-term crop rotations far superior in protecting soils on a Washington State farm than were the methods of continuous cropping used on a neighboring farm (Reganold, 1988). In general, crop rotations boost yields by about 10 percent. Consider also figures that show insect pheromones protecting grapevines in New York from the grape berry moth, without the possible side effects of chemical residues in either food or water.

Often these methods are called "low-input" approaches to describe the lower amount of off-farm, purchased inputs used (Francis and King, 1988). In another sense, however, such methods could also be called "high-input" because they are information- and management-intensive. Greatest resource efficiency can be achieved by seeking site specificity and by taking advantage of each unique combination of resource, climate, and marketing conditions and possibilities.

Repeatedly, surveys have shown strong farmer interest in learning about low-input farming methods. The 1989 Iowa Farm and Rural Life Poll conducted by the Iowa State University Extension Service, for example, found that three-fourths of 2,007 Iowa farmers surveyed thought that farming relied too heavily on chemical

fertilizers and pesticides; 56 percent said farms would use more low-input methods if more research information were available. "Sustainable farming" groups, formed to facilitate farmer-to-farmer information sharing, have sprung up across the Midwest. The Kerr Center for Sustainable Agriculture in Oklahoma found, in early results of a recent survey, that a majority of farmers were interested in having their land used for low-input research. In this regard, it is important to note that researchers are now documenting the fact that on-farm research can produce results scientifically comparable to experiment station research (Rzewnicki et al., 1988). And on-farm research has much added value in its educational relevance for farmers, as well as direct feedback of farmer experience to researchers.

Myths About "Low-Input" Agriculture

However, along with the promise of low-input methods and their obvious workability in many instances, there exists much skepticism and misunderstanding about the characteristics of "low-input" agricultural methods and about "sustainability" as a goal. There is, indeed, a long list of erroneous stereotypes about such approaches. Among these are the following (Francis and Youngberg, 1989):

- "Low-input farming equals low-output farming." This remark is designed to show that "low-input" can't work economically. On the contrary, while yields sometimes are lower, that is not always the case. During drought conditions or other yield-limiting circumstances, systems with reduced input costs often have higher net profits on any type of farm.
- "Low-input farming equals organic farming." Not so, since many low-input managers continue to use synthetic chemical fertilizers and pesticides, albeit at much lower levels. Integrated pest management, for example, does not always eliminate the use of synthetic chemicals, even though it reduces them.
- "Low-input farming means going back to the past, to mules and horse-power." Again, this is a myth. Low-input operations are scientifically sophisticated, often involve computer-based calculations and the very latest innovations in conservation, cropping practices, improved seed, and livestock feeding and handling. Although they use some methods from the past, they integrate these methods into today's knowledge and technical framework.
- "These low-input methods are only for small farmers." Here, we respond by listing several examples: North Dakota low-input wheat producer Fred Kirschenmann farms 3,000 acres; Nebraska low-input cash crop farmer Del Akerlund operates on 700 acres; Iowa livestock and crop producers Richard and Sharon Thompson farm 300 acres. Other examples of relatively large-scale low-input farmers are too many to list. An obvious area which has not had much research or on-farm experimentation is in larger acreages of vegetable crops such as peppers or tomatoes. There is a current move by some large California vegetable growers to reduce or eliminate chemicals from their operations.
- "Reducing inputs means doing it all at once." By contrast, most low-input farmers are very aware of what is called the "tran-

sition" process and generally evaluate and weigh each step in what may be a multi-year process of shifting input levels. As with any prudent change in management, most farmers use these new low-input methods initially on a few acres rather than on the whole farm simultaneously.

Panel to Formulate Guidelines and Criteria

Often, it seems, these misconceptions arise as a result of the erroneous belief that a small group of "alternative agriculturists" is trying to take over the U.S. farm agenda for their purposes. In fact, insofar as sustainable agriculture is a goal, the very best efforts of the entire agricultural community will be needed. Consequently, it is important that the sustainability agenda not be seen as the agenda of a minority. Partly for this reason, it is increasingly important that the concept of sustainability have clear criteria. Without an agreed upon set of criteria, we fear that use of the term, even as a goal, could become more political than scientific.

With this in mind, the Institute for Alternative Agriculture has suggested that the Agriculture committees of both House and Senate appoint a broadly representative panel of experts to formulate preliminary guidelines and criteria for use in judging the relative impacts on sustainability of existing and future farm bill proposals.

Such a panel might, for example, decide that economic sustainability could be measured by comparing past farm performance with performance under new methods: the output per unit of input; the achievement of an adequate profit for the farm owners; the achievement of adequate yields per acre, given the need for profitability. These are only very rough ideas, but they give some sense of what might be used as criteria of sustainability.

With such sustainability criteria in place, research and education authorized in the 1990 farm bill could be evaluated more objectively. It is clear that no single set of currently available systems and technologies should claim to hold an exclusive key to the ultimate, long-term goal of agricultural sustainability. Merely labeling a particular production method "sustainable" does not guarantee that it really is, nor does the label mean that some other approach or some future combination of emerging technologies cannot also contribute to the goal of sustainability.

Using the concept of sustainability in combination with the development of preliminary guidelines for measuring its achievement could produce a number of extremely important results. It could demonstrate and test the utility of sustainability as a consensus term in agriculture; it could marshall and focus the creative energy and intellect within our agricultural institutions as they grapple with the questions of what is a sustainable system and how we can create programs and policies that can achieve that goal; it could help Congress and other policymaking institutions make better decisions with regard to a whole array of questions, including commodity provisions and research priorities; and it could generate a much-needed measure of cooperation within agriculture– a political precondition if the industry hopes to flourish in this time of severe budget restraint and international competition.

Perspectives on Sustainability

The following papers, written by leaders in the farm policy, research, and education community, detail the need for Congress to support new and more sustainable directions for U.S. and world agriculture. They provide additional specific evidence of methods that are proving to be more sustainable, and also give recommendations for Congressional action. The papers are followed by viewpoints from farmers in every State of the Nation. Together, they make a strong case for supporting and funding action that will make sustainability an integrating goal for the American farm and food system.

Robert Rodale calls for a preventive approach to weed and pest management and at the same time to reducing resource degradation. Conventional agriculture, he argues, typically approaches management through treatment of problems; for example, it uses insecticides to control pests already in the field. In contrast, preventive farmers focus on devising methods such as crop rotations, resistant crops, or variations in planting times that deter or prevent development of insect and disease problems. Focusing Federal research efforts on prevention could yield large gains in the long-term productivity and profitability of American agriculture, Rodale says. He calls for stronger farmer/researcher partnerships to identify specific research goals and suggests that research funding and the overall research agenda too often come from suppliers of farm inputs. Policymakers must correct this bias by pushing for a cooperative approach to a truly preventive agricultural system.

Focusing on pest management, Marjorie Hoy argues that biological control methods, defined as insect and disease suppression with living organisms, have been proven cost-effective and often are self-sustaining. While broad spectrum pesticides are usually disruptive to biological control agents, use of biological controls is compatible with both conventional and low-input agricultural systems, she says. Using low levels of selected pesticides in ways that do not disrupt biological controls could yield substantial improvement in pest control even without development of new technologies. Despite the promise of these methods, they are insufficiently utilized. Badly needed research efforts are not adequately funded, and no coordinated national program exists in this area. Overall, because ecological studies may require 10 years or more to provide answers, Hoy points to the essential need for long-term funding.

As a broader approach to reducing crop losses, "integrated pest management" (IPM) refers to a series of methods across the entire spectrum of current techniques ranging from natural predators to chemical pesticides, according to George Bird. The current national IPM research program is funded at $3 million from the Special Grants Section of PL 89-106, with monies made available to 177 scientists at 44 institutions. Bird projects that the major pest management strategy in sustainable agriculture will be pest avoidance through system design. The current assumption that pest control with IPM will be done only by the farmer is an important obstacle to present use of IPM tactics. These techniques often require familiarity with extensive and complex information, plus routine and careful scouting and monitoring of pest problems. Bird projects

that the sophisticated nature of pest management will necessarily require the services of professional plant and environmental health specialists who will operate rather like veterinary doctors. To provide additional professional training and to generally support IPM methods, he calls for development of a National Center and four Regional Centers for Plant and Environmental Health.

The importance of diversity in crop production is described by David Bezdicek. He points out that our current industrialized monocultures may have caused reductions in biological diversity and losses in productivity that can be restored only at great cost. Alternatives such as crop rotations and greater diversity of crop and animal enterprises, he argues, can lead to a more sustainable and profitable operation for the individual farmer. Crop rotations can take advantage of natural or internal biological interactions to control a number of weed, insect, and pathogen problems as well as contribute to long-term soil fertility. Bezdicek points out that diversity of crop species as well as incorporation of animals in mixed systems can promote greater soil organic matter and lead to more closed nutrient cycles. He concludes that properly designed rotations can help the manager make more efficient use of internal resources and solve some of the environmental problems created by excessive use of external inputs, yet farm policy needs to be designed to favor this approach.

One particular research and education program funded by USDA and authorized by the 1985 farm bill, the Low-Input/Sustainable Agriculture (LISA) Program, is specifically evaluated by Brian Chabot. LISA has been described as the single most visible USDA program, and numerous States have established State funding to match the Federal initiative, Chabot says. In his own State of New York, farmers are volunteering time, land, equipment, and ideas in support of the program, which they see as helping create positive options on an immediate and practical level. Chabot refutes the myths that LISA research is aimed at eliminating farm chemicals (LISA supports research that lowers but does not necessarily eliminate all chemicals) and that it is a return to the past (LISA-supported systems use sophisticated, up-to-date scientific information). He argues for reauthorization of LISA in the 1990 farm bill, with inclusion of language that incorporates current program objectives and administrative arrangements. A formal program integration should be set up between LISA and Federal IPM and water quality programs, Chabot suggests.

Public concern about health-risk factors in the U.S. food supply is at an all-time high according to Michael Jacobson and Dan Howell of the Center for Science in the Public Interest. In their view, concern for food safety is significantly affecting the food choices currently being made by shoppers in retail food stores. Apprehensions of consumers about residues of pesticides and other ag chemicals in foods is a part of the problem; recent events relating to Alar in apples and apple products offer a case in point. Another aspect of the situation relates to concern about possible residues in meat of growth-promoting hormones used in the raising of beef cattle. In addition, foods of high saturated fat content, e.g., some products derived from beef, pork, and whole milk, are being avoided because of their alleged tendency to clog human arteries and in-

crease the risk of heart attack. A sustainable agricultural system, according to Jacobson and Howell, must take these health risk matters into account by providing consumers with lower-risk food alternatives. Consumer groups, agricultural policymakers, food safety regulators, food retailers, people involved in the testing of food safety, and many others are all exhibiting interest in what is going on. Sales of organic foods are showing dramatic increases. The situation involves both problems and opportunities for food-producing farmers in the future.

Finally, the implications for U.S. agriculture of changes in the agricultural sector on an international level are charted by Richard Harwood. Perceptible overseas shifts include increasing recognition of the need to use scarce and expensive resources efficiently and to conserve nonrenewable resources. Congress can help U.S. agriculture take a leadership position in future world agriculture by creating clear mandates and well-focused but modest programs, according to Harwood. He recommends increasing cooperative involvement between land-grant institutions and farmers as well as with nongovernmental organizations. At present, on-farm work in Asia has left the U.S. scientific community well behind, he says. Experience in the integration of systems to optimize production with minimal inputs of manufactured products is crucial to Third World nations, and is another area in which U.S. leadership needs to be developed.

Harwood proposes a small grants program, associated with LISA, that would have a Third World research direction. This program would be aimed at training groups of applied scientists at land-grant institutions who would become experts in sustainable approaches that could be common to both U.S. and Third World agriculture. The United States could also take leadership by aiding other nations in the creation of resource quality data bases and by developing the capacity to analyze appropriate location and scale of farm enterprises to protect the environment and achieve socioeconomic goals.

Agribusiness opportunities and dangers are also forecast by Harwood. U.S. exports to Europe will come under increasing scrutiny and lead to reduction of pesticide use, he projects. Harwood also predicts that export of farm chemicals now banned in the United States is likely to come under increasing political pressure, especially since nearly all chemical use in Third World countries is by hand application.

Harwood's challenge, that retaining world leadership in the area of agriculture will demand evolving rapidly toward greater sustainability, indicates the scale and opportunity of the sustainability issues facing Congress in the formulation of the 1990 farm bill. In different language, each of the contributors here clearly supports a future farm program that increases the range of management options available to farmers, and this is possible only with the long-term goal of sustainability in clear focus.

At this juncture, Congress can choose to clearly and decisively support programs aimed at achieving the goals of agricultural sustainability. This will assist U.S. farmers, support broad environmental/social goals, and simultaneously assure our farmers and agricultural scientists and educators of their world leadership role. A

strong momentum is building among the farm, conservation and environmental community, and consumers in support of that idea. The other alternative, not recommended by any authors here, is for Congress to ignore this opportunity and approach the 1990 farm bill as a simple updating of agendas carried forward from the past.

Rethinking farm programs and strategy takes a great deal of work. Developing the political consensus for an appropriate direction to gain more sustainability in our farm and food sector takes a cooperative approach. This, too, can be time and energy consuming. Such constraints notwithstanding, this Congress has an opportunity to make an historic mark in agriculture by choosing a clear course of support for economic, environmental, and social sustainability in America's farm sector.

References

American Society of Agronomy. 1989. Decisions reached on sustainable agriculture. Agron. News, January, p. 15.

CAST. 1980. Organic and conventional farming compared. Council for Agricultural Science and Technology, Report No. 24, Ames, Iowa, October. 32 pp.

CAST. 1988. Long-term viability of U.S. agriculture. Council for Agricultural Science and Technology, Report No. 114, Ames, Iowa, June.

Edwards, C.A., R. Lal, P. Madden, R.H. Miller, and G. House, editors. Sustainable Agricultural Systems. Soil & Water Conservation Society, Ankeny, Iowa.

Francis, C.A., C.B. Flora, and L. King, editors. 1989. Sustainable Agriculture for Temperate Zones. John Wiley & Sons, New York, New York.

Francis, C.A., and J.W. King. 1988. Cropping systems based on farm-derived, renewable resources. Agr. Systems, U.K. 27:67–75.

Francis, C.A., and I.G. Youngberg. 1989. Sustainable agriculture—an overview. In: Sustainable Agriculture for Temperate Zones, C.A. Francis, C.B. Flora, and L. King, editors. John Wiley & Sons, New York, New York (Chapter 1).

Harwood, R.R. 1989. History of sustainable agriculture: U.S. and international perspective. In: Sustainable Agricultural Systems, C.A. Edwards, R. Lal, P. Madden, R.H. Miller, and G. House, editors. Soil & Water Conservation Society, Ankeny, Iowa.

Madden, J.P. 1989. The economics of sustainable low-input farming systems. In: Sustainable Agriculture for Temperate Zones, C.A. Francis, C.B. Flora, and L. King, editors. John Wiley & Sons, New York, New York (Chapter 11).

Reganold, John P. 1988. Comparison of soil properties as influenced by organic and conventional farming systems. American J. Alternative Agr. 3(4):144–155.

Rzewnicki, P.E., R. Thompson, G.W. Lesoing, R.W. Elmore, C.A. Francis, A.M. Parkhurst, and R.S. Moomaw. 1988. On-farm experiment designs and implications for locating research sites. American J. Alternative Agr. 3(4):168–173.

USDA. 1980. Report and recommendations on organic farming. U.S. Department of Agriculture, July. 94 pp.

USDA. 1981. A time to choose: Summary report on the structure of agriculture. U.S. Department of Agriculture.

SUSTAINABILITY: RESEARCH AND EXTENSION

AGRICULTURAL SUSTAINABILITY RESEARCH NEEDS AND PROGRESS

(By Robert Rodale, Chairman of Board of Rodale Institute)

Farmers who use low-input, sustainable and regenerative methods have been separated from the main stream of the agricultural science and research community for several generations. These farm operators have looked at and used agricultural science with an outsider's perspective. They have taken only what they wanted, and ignored the rest.

That period of isolation began to end about 10 years ago. And within the last few years, the users of these methods and their special needs began to come into the full view of agricultural leaders.

Why? What did they see when they took a look at the farms using low-input and sustainable methods?

First, they saw that productivity was good. Sometimes even better than comparable conventional farms.

Then, they noted that the quality of the land was being maintained, or improved. And, because of lower cost for inputs and their adequate yields, the economic situation of these farms was healthy, and these farmers and their neighbors were living in a healthier environment. There was little or no spray drift, and less pollution of ground water caused by leaching of nutrients and pesticides.

How have low-input, sustainable farmers been able to achieve these remarkable results, while being separated from much of the technical and scientific help available to conventional farmers?

There is a simple answer. They took a preventive approach to their problems. These farmers invented what I call preventive agriculture. Perhaps invented is the wrong word. They simply copied the cost-saving and productivity-increasing preventive approach used widely in many other fields, ranging from medicine to traffic safety to industrial maintenance. For example, rather than resorting to herbicides to knock out weeds, many farmers combine timely cultivation with variations in planting dates and seeding rates to produce thicker canopies at just the right time to shade out weeds.

Here is how it happened. Farmers—whether they consider themselves low-input, sustainable, regenerative or organic—almost always find themselves able to begin their operations using most of the basic tools and physical concepts of modern agriculture. They purchase standard tractors and many of the same implements as conventional farmers. They select their seeds from the standard inventories of seed companies. And they buy supplies from local cooperatives and dealers.

Sustainable farmers are often among the very first to adopt or at least try "new technology" such as ridge-tillage and improved seed varieties. Sustainable farmers seem to have the panoramic vision

to match the best classical farming methods such as crop rotation with the newest equipment and practices.

When they operate their farms, though, these low-input, sustainable farmers know that if they get in trouble, they are going to have to find their own way out. Many are reluctant to call the Extension Service for help. Because if farmers say, "I have a bad attack of *x* bug in my *y* field," the remedy suggested will almost always involve use of a treatment or chemical they will find unacceptable.

So these farmers have learned over the years to build a wide range of preventive techniques into their farming systems. How to prevent infestation of *x* bug in the first place, for example. That is not to say that conventional farmers do not also use some preventive methods, they do. For example, the use of a preemergence herbicide could be interpreted as a preventive measure against a weed infestation.

But there is a big difference in the overall approach of each type of farmer. The conventional farmer uses preventive methods occasionally, within a matrix of a system that is overwhelmingly treatment-oriented, while the low-input, sustainable farmer sees and uses prevention as a life-or-death set of methods. Without effective prevention, the operation will probably experience severe financial setbacks. So obviously the farmer sees prevention as the vital step or steps beyond which failure often lies.

The "low-input" label often applied to this way of farming paints a distorted picture of sustainable agriculture. While it is true that sustainable agriculture uses fewer farm chemicals, farmers practicing preventive agriculture make much greater use of other inputs like legume seed, machinery, and information than conventional farmers. That is especially true of information. "How can I *prevent* a weed problem?", is the way regenerative farmers approach weed control. Success requires a thorough knowledge of weed cycles, tillage options and a good measure of common sense.

Farmers who rely overwhelmingly on preventive techniques have put together large elements of what could be called a preventive agriculture system. They are using so many different preventive methods that they all interlock and fuse together into a preventive whole. And that unified preventive system of farming creates more benefits for the farm operators than the sum of all the individual methods analyzed separately. In addition, some of the preventive agriculture methods of the sustainable agriculture community are systematic by their very nature.

That is particularly true of crop rotation, the most obvious and beneficial preventive agriculture technique used in sustainable and regenerative agriculture. When the same crop is planted in the same field year after year—common in conventional agriculture—plant disease organisms, weeds, and insects have a clear field. Their life cycles are not interrupted. They have the same food to eat year after year. Monocropping, therefore, is a system the pathogens, weeds, and destructive insects might have designed to enhance their own welfare.

When crops are rotated, though, the whole system is changed. Life cycles of pests are interrupted frequently—sometimes even by plants and other organisms that destroy them. There can also be

starvation among the pests, an outcome devoutly welcomed by farmers. But that is not by any means the limit to these benefits. Soil fertility can be increased if leguminous plants or green manures are included in the rotation. Increased levels of humus in the soil help to prevent damage to plants by both drought and excess rainfall. Erosion is often reduced or prevented by rotations that include a period of sod cover.

Preventive agriculture is particularly helpful in solving weed problems. Weeds are a tremendous problem for modern-day farmers in this country. Weeds cause enormous crop losses (about 8 per cent) and the treatment of weed infestations with herbicides is responsible for a large part of the growing ground water pollution problem.

Almost all the conventional research and Extension efforts in the weed control area are directed at treatment. Use of herbicides is considered to be both the first and last line of defense in almost all conventional farming systems, although cultivation has begun to come back into vogue in a small way.

Farmers classified as low-input, sustainable, regenerative or organic use a variety of preventive weed control techniques. Crop rotation is their starting point for weed prevention. That method of varying the environment, forcing weeds to compete with crops in a wide variety of environments, simplifies the control challenge.

But low-input farmers also try to time plantings to give their crops a jump on potential weed infestations. They also have learned to interplant crops like soybeans into grain crops in some areas, to crowd out weeds. Where appropriate, sustainable farmers also use ridge-tillage, which creates a smaller planting area where intensive weed control methods are needed. On the slopes of the ridges, weeds that do grow interfere less with crops. In some cases, they have even learned to turn the weeds scorned by more conventional farmers into profitable crops. Amaranth, which exists as both a noxious weed and (in different form) a profitable crop, is a good example of a very innovative approach.

Research Policy Options To Enhance Preventive Agriculture

Large gains could be made quickly in the productivity of American agriculture if Federal agricultural research policy would become more prevention oriented. And if the creation of agricultural prevention systems become a goal of interdisciplinary efforts. However, any effort to plan for that change must include a clear understanding of the unique economic perspective of sustainable and regenerative farmers.

They know that they are able to compete in a comparatively unfriendly ag-science environment only by maximizing the value and vitality of their internal resources. These internal resources are embodied in the land of their farms, the air, the water and their own skills and management heritage. In other words, the things any farmer gets with the farm, and pays for only once.

I will mention one specific example—the nitrogen in the air. Most sustainable farmers are aware that air contains 78 percent nitrogen. They also know that by using leguminous plants in their rotations, and by recycling nitrogen within their system, they can

avoid the purchase of most or all of the nitrogen fertilizer needed by other farmers.

They therefore manage their farms in ways that *prevent their need to purchase nitrogen fertilizer.*

And if they do find themselves needing nitrogen fertilizer, these farmers want to use it in ways *that prevent the deterioration of their capacity to make maximum use of their own nitrogen resources.* Many farmers are convinced that the free-living, nitrogen fixing bacteria in the soil get lazy when nitrogen is overused.

Do conventional farmers think that way? Very seldom, if ever. They are partners in a research, Extension and supply system oriented very directly to the maximization of yields. And to get the high yields the system aims to make possible, maximization of input use is tolerated, and often encouraged.

That fundamental difference in economic perspective suggests two important insights for makers of Federal research policy.

The first insight is the difficulty of picking research advances from a menu of conventional agriculture accomplishments and saying that they are important to low-input, sustainable and regenerative farmers. That has been done often by managers of conventional science, and has always caused chuckles or frustration among sustainable farmers.

They can see that many of those so-called advances are treatments, not preventives. Or that they are methods useful in a conventional system, but hardly relevant to the improvement of a preventive agricultural system. Or—and this is the most frustrating—that these scientific advances merely enhance production at the expense of the vitality of the farm's internal and financial resources.

The second potentially important insight for policy makers is that the preventive orientation that sustainable farmers have adopted and worked to perfect *has tremendous potential to speed improvement in the conventional agriculture system.* You don't necessarily have to be a sustainable/regenerative farmer to reap the benefits of a preventive approach. There are many ways that conventional farmers can use preventive methods and systems as well.

There is also a tremendous potential for low-input, sustainable and regenerative agriculture to create new jobs. Private crop consultants who specialize in preventive agriculture now report having more business than they can handle. So does an Iowa fertilizer dealer I know who specializes in helping his customers "spend less and make more." Sales are booming for makers of machinery used to control weeds and even insects without chemicals. Many seed companies are enjoying a brisk business in legume and other seeds for cover crops. Growing consumer demand for farm-fresh food grown with fewer chemicals is also creating many new jobs in the areas of processing, handling, and retailing.

Given the right information, almost all farmers could do more to *prevent* infestations of insects, weeds and other problems. Large numbers of farmers could also use better methods for preventing the constant deterioration of their resource base. But that change in orientation could take a long time to happen, given the deeply ingrained treatment mentality in almost all participants in the conventional agriculture system.

Research Needs of Sustainable/Regenerative Farmers

Farmers with experience using sustainable/regenerative methods have attended several forums on research policy during the past year. These areas for additional research or for increased research emphasis were mentioned frequently during those meetings:

1. *More efficient nutrient cycling within the farm system, and development of new ways of satisfying nutrient needs.* There has been much controversy in this area. The conventional research mindset often closely matches that of the fertilizer industry. Emphasis is placed on the goal of maximum yields, requiring heavy additions of fertilizers. The sustainable/regenerative farm community is seeking participation in nutrient management philosophies that focus, instead, on the best economic return, use of the soil's internal capacity for regeneration, and minimization of damage to ground and surface water.

2. *Development of better cropping systems, with a stronger emphasis on innovative crop rotations.* There is a clear awareness that the abandonment of many rotations has unnecessarily weakened the capacity of farms and farmers. More work is also requested on ways to integrate farm livestock in sustainable systems.

3. *Weed prevention and control.* New ideas and methods are especially needed here, considering the growing awareness of environmental problems connected with use of herbicides.

4. *Prevention of plant disease.* This is a high priority of many farmers.

5. *Insect problems.* More preventive methods are needed. Such work is particularly important now, as many conventional farmers will be seeking to convert to sustainable methods, and will be inexperienced in the prevention strategies learned over many years by other farmers. New methods of sharing information among farmers will be needed.

6. *Market development.* There is a growing market for meat and other agricultural products that are free of added growth hormones, antibiotics and pesticide residues. There is also a new market for animals raised in nonconfining environments. These new markets create opportunities for market development, if researchers and Extension workers can be motivated to provide the necessary help to farmers.

7. *Diversification opportunities.* Sustainable, regenerative and organic farmers are in an excellent position to capitalize on diversification opportunities. The low-chemical or no-chemical products they produce are exactly in tune with consumer interest in so called "clean" foods and a greater variety of fresh-from-the-farm ingredients. That creates a need and an opportunity for new crop and farm product improvement. But it has to be undertaken with the specific needs and opportunities of this farm-production sector in mind.

Five Years From Now, Writing Papers on This Theme Should Not Be Necessary

We have in the United States a large capacity to conduct agricultural research, the best area of farm land in the world, in a good

climatic area, and a sufficient number of motivated and experienced farmers. That's the good news.

The bad news is that U.S. farmers are plagued by problems that even a far less qualified and well-funded group of researchers should be able to solve. We're simply not using our vast research capacity enough or in the new ways called for by today's challenges.

Why not?

Because researchers and farmers don't work together well enough. Certainly, they lack the kind of partnership spirit that typifies research-producer efforts in other fields.

Theoretically, a system is in place to connect the two groups. Extension exists (on paper) for that purpose. Researchers are supposed to use Extension both to tell farmers how to solve their problems, and to listen to farmers about their needs. The problem is that Extension people are much better at telling than they are at listening. And even when the researchers do hear what farmers want in the way of preventive methods (for example), they know full well that the farmers' voices carry no funding. While the voice of suppliers of farm inputs echoes with a generous history of financial support for research programs.

As a result, a continual policy correction process is needed. Makers of research policy now must spend valuable time and energy trying to play a mediating role. Recurring environmental and economic problems with agricultural roots shout for analysis, and for correction.

A truly preventive agricultural system would be much more unified, and marked by cooperative efforts. The kind of farmer-research partnership that has been pioneered by the LISA program would characterize all of agriculture. The efforts at mediation that now eat up so much time and energy by people outside the production-innovation loop could then be directed to other challenges.

We now know that the potential for a very large scale preventive program for agricultural problems exists. It is time to turn that potential into reality.

THE IMPORTANCE OF BIOLOGICAL CONTROL IN AGRICULTURE: AN UNDERUSED AND RENEWABLE NATURAL RESOURCE

(By Marjorie A. Hoy, Department of Entomology, University of California at Berkeley)

Current Status of Biological Control

Biological control is pest and disease suppression with living organisms. It is applicable to insect pests, plant pathogens, nematodes, and weeds.

Crop yields in the United States are reduced by the impact of a variety of pests. Weeds are potentially the most damaging, followed by approximately 8,000 species of insects, followed by plant pathogens and nematodes. Partial or complete control of these pests has been achieved through a variety of methods, including chemical, cultural, and biorational controls. Biological control has provided excellent control of some pests and has the potential to control many others.

Biological control has unique advantages over chemical control. Biological control has been defined as the "actions of parasites, predators, antagonists, and pathogens in maintaining another organism's density at a lower average than would occur in their absence". It often provides a self-sustaining, balanced system which maintains pest populations at nondamaging levels without the need for additional inputs. In some cases, biological control requires periodic intervention, and biological control agents must be applied repeatedly or be reintroduced. Although the concepts of biological control are simple, the interactions among the environment, pest, and biological control agent may be complex.

Biological control is common, not the exception. Many organisms are not pests because mechanisms such as *natural biological control* keep them suppressed with no assistance from humans. We often don't recognize the benefits of natural biological control until it has been disrupted, which often happens after the application of chemical pesticides. The term biological control thus refers not only to an applied technology through which humans attempt to restore, to enhance, or to mimic a natural phenomenon, but also to a natural one. Despite the facts that biological control and plant resistance are cornerstones of integrated pest management (IPM), and that biological control must be an integral component of low input sustainable agriculture (LISA), biological control is an underutilized natural resource. Research to incorporate biological control into IPM and LISA is limited, and funding for such effort is scarce. Program managers of past national efforts to foster integrated pest management supported projects that focused on research designed

to time pesticide applications effectively, model plant/pest interactions, identify and/or refine economic injury levels, and predict pest populations. These subjects certainly deserve attention. However, funds for biological control probably have constituted 20 percent, or less, of the funding allocated to IPM programs and support in LISA programs also appears limited.

Why Biological Control?

Biological control offers several advantages over other pest control approaches. Although biological control cannot totally replace chemical pesticides, a broader use of biological control has many advantages. *Biological control is generally compatible with other management tactics,* including plant resistance, cultural controls, and other biorational methods. Biological control organisms are environmentally safe, non-polluting, and usually affect only the targeted pest or disease organism, thus helping to preserve endangered species and biological diversity. Biological control can often provide an effective alternative to many chemical pesticides. The use of biological control can extend the useful life of needed chemical pesticides by slowing the emergence of pests that are resistant to the chemical. *Biological control is compatible both with conventional and low input sustainable agriculture and is crucial to organic farming. It is cost effective and often self-sustaining.*

Why Aren't We Using Biological Control Now?

We are, but at a level that is much too low. Several factors have limited progress towards a wider reliance on biological control approaches. Broad spectrum pesticides are usually disruptive to biological control agents. Broad spectrum pesticides provide rapid and dramatically visible control whereas biological control agents are more diverse, may require unique methods of application or release protocols, and *reduce* pest populations rather than eliminate them. Thus acceptance of biological control tactics requires education of the user. Motivation to accept biological control has been low, although recent concern about ground water contamination, food safety, endangered species, and enhancing the sustainability of agriculture has resulted in heightened interest in this approach to pest control. Biological control tactics are often specific; one organism may control only one pest. The specificity of many biological control agents limits their attractiveness for commercialization. Some biological control agents have no potential for commercialization since they need only be applied once to become established and to provide more or less perpetual suppression.

However, even if all the social, economic, and perceptual barriers to the use of biological control were removed instantly, research and education programs to enhance the use of biological control would still be needed. The discovery and development of biological control agents requires investment in new research but no primary funding source is available currently to support this research. No coordinated national program exists to foster development of biological control organisms or tactics. There is a lack of basic knowledge about the biology, ecology, and taxonomy of pest insects, pathogens, nematodes, and weeds and their biological control

agents and associated complex interactions. For a long time, priorities in agriculture have been directed towards maximizing production in the short term rather than sustaining agriculture in the long term. The challenge today is to improve competitiveness without sacrificing environmental quality. Biological control can help meet this challenge. Research to expand our knowledge of biological control should involve a balanced, but diverse, array of disciplines ranging from ecology, systematics, population genetics, biochemistry, behavior, agricultural economics, and molecular biology. Research efforts must include laboratory and field investigations and studies to develop methods for extending and utilizing the new knowledge.

How Do We Use Biological Control?

There are three main tactics in biological control—classical, augmentation, and conservation. Efforts to increase the use of all three tactics in U.S. agriculture are critically needed.

CLASSICAL BIOLOGICAL CONTROL

"Classical" biological control is based on the targeted exploration for natural enemies (parasites, predators, pathogens, or antagonists) of introduced pests and the importation and long term establishment of the natural enemies in the new environment. The goal is to provide continuing control of the exotic pest arthropod, pathogen, nematode, or weed. This approach to biological control has been rewarding; hundreds of successful projects have reduced damage caused by a wide array of introduced pests. In addition, once a successful program is achieved in one location, the same natural enemies are frequently used to control the same pests elsewhere in other climatically similar locations. Natural enemy importation thus remains an important and effective tactic in biological control. Unfortunately, *classical biological control has received less support than it deserves.*

While many biologists are concerned over the extinction of animal and plant species in ecosystems, agricultural pest management specialists are concerned about *additions* to the fauna and flora of agroecosystems. In 1971, the U.S. Department of Agriculture established a task force to review the effectiveness of plant quarantines in preventing the entry of exotic pests and to quantify the risks associated with the entry of such pests and diseases. A list of immigrant insects and related arthropods in the United States was compiled, and categorized the immigrants as pests, beneficial species, and those of no known economic importance. At the conclusion of the 1971 study, 1,115 species were recognized to be of foreign origin and this number had increased to 1,385 by 1977. The list continues to grow as additional insect and mite species are intercepted and identified. Foreign insect and mite species are considered to be responsible for a substantial share of crop losses; one estimate is that they are responsible for 50 percent of such losses in California. When viewed nationally, foreign species comprise 39 percent of approximately 600 important arthropod pest species. An additional 630 foreign arthropod species are on the list as pests of lesser importance. Exotic invaders include such important major

pests as the Japanese beetle, European corn borer, codling moth, wheat rust, Dutch elm disease, chestnut blight, gypsy moth, cottony cushion scale, California red scale, red imported fire ant, Russian wheat aphid, crabgrass, Johnsongrass, and boll weevil, just to name a few.

Foreign pests probably will continue to invade the United States, despite the efficacy of the national quarantine system. It is estimated that 11 arthropods will invade the United States each year, of which 7 are likely to be pests of some importance, and about every third year an exotic pest of major significance will invade the United States. Assuming that many of these pests are not (or cannot be) eradicated, classical biological control will remain of primary importance in controlling new exotic arthropod pests in forests, range lands, and agriculture.

Classical biological control of arthropod pests has been actively practiced for about 100 years in the United States. Estimates of success range from 16 to 34 percent. A variety of factors affect success in classical biological control programs, which include climate, natural enemies, habitat type, genetics, host compatibility, host phenology, and operational procedures. While classical biological control is effective and has yielded complete and lasting control in a variety of important situations, many aspects of this pest management tactic require additional research. Many attempts have been only casual or have involved use of an unsuitable natural enemy. The possibilities for controlling the notorious coding moth in this way, or the Mexican bean beetle, or the cotton boll weevil, for example, have been explored only superficially.

There are many opinions as to what the research priorities in classical biological control should be. There is little argument that classical biological control has been underexploited and underfunded. In one sense, classical biological control has been oversold; the dramatic cases in which complete biological control has been achieved through a small investment in research funds has, in my opinion, resulted in unrealistic expectations as to the resources needed to properly conduct classical biological control programs. This could be labeled the "cottony cushion syndrome".

The cottony cushion scale threatened the citrus industry in California in the late 1800's. This exotic species was suspected to be from Australia and a very small amount of funding ($2,000) was obtained to support a field agent's search for natural enemies in Australia in 1888. A parasite and a small lady beetle (then called *Vedalia*) were found attacking the scale in the Adelaide area of Australia, and 129 beetles were shipped to California. There they were placed on a small infested citrus tree enclosed in a mesh tent in January 1889. By early April the scales were controlled on the caged tree and by early June over 10,000 beetles had been distributed to various southern California groves. By the end of 1889 the *Vedalia* beetle had cleared the scale pest from hundreds of citrus acres.

Most classical biological control programs probably require substantially more time and resources than were necessary for this project, yet such resources are rarely provided. However, *if such resources were provided, it seems likely that both the rate of establishment and rate of success in classical biological control of arthropod*

pests and weeds can be increased, thus providing long term, economical, and environmentally sound control of exotic pests.

AUGMENTATION

Augmentation involves efforts to increase populations or beneficial effects of natural enemies of both native and exotic pests. Augmentation involves various techniques, including periodic releases and environmental manipulation. Environmental manipulation may include provision of alternative hosts or prey, use of semiochemicals (chemical cues) to improve natural enemy performance, provision of environmental requisites such as food or nesting sites, and modification of cropping practices to favor natural enemies. Augmentation has been particularly successful in glasshouse crops.

Inundative releases are designed to control a pest by the actions of the released natural enemies, not by the actions of their progeny, and thus can be considered "biotic insecticides". While microbial pesticides can be commercially produced and effectively used in inundative releases against specific insect and weed pests, our limited ability to produce high quality, inexpensive, mass-reared natural enemies limits the use of this biological control tactic. Advances in current research on synthetic diets, artificial hosts, quality control, and genetic manipulation could result in increased use of inundative releases of natural enemies.

Another emerging technology is the use of semiochemicals (chemical cues) to improve the efficacy of natural enemies in augmentation schemes. Parasitic insects use various chemical cues to locate their hosts. Recent research indicate that learning can modify the responses of parasites to these chemicals. The complexity of host seeking behavior exhibited by natural enemies is only beginning to be understood and could lead to the more sophisticated use of natural enemy augmentation.

CONSERVATION

Conservation involves protecting and maintaining natural enemy populations. Conservation is crucial if we are to maintain the naturally occurring biological control of many potential pests. Conservation is also crucial if introduced natural enemies are to be maintained in agricultural systems. Most commonly, conservation involves modifying pesticide application practices so that they are used only when pest populations exceed specified injurious levels. In some cases, conservation of natural enemies can be achieved by altering the active ingredient, rates, formulations, timing, and/or location of pesticide applications. Or, existing populations of natural enemies can be protected by maintaining refuges. It is probable that the most dramatic increase in the utilization of biological control could come through the judicious use of selective pesticides. While we can use pesticides selectively in some crop systems, we lack the ability to do so in many other cases. However, as long as key pests cannot be controlled biologically, culturally, or through host plant resistance, some agricultural chemicals will be needed. *Learning how to conserve natural enemies in the agroecosystem is a relatively rapid and cost effective way to increase the use of biologi-*

cal control in agriculture and to reduce pesticide use while maintaining crop yields and quality.

EMERGING TECHNOLOGIES

Genetic manipulation of parasites, predators, pathogens, and antagonists offers promise of enhancing their efficacy in agricultural cropping systems. Genetic manipulation of other beneficial arthropods, such as silkworms and honey bees, has been conducted for hundreds of years. Genetic manipulation of biological control agents seems to be a logical extension of the domestication of crop plants and animals that have been part of agriculture for thousands of years. As in crop breeding, three potential genetic manipulation methods exist: artificial selection, hybridization (use of heterosis), and recombinant DNA (rDNA) techniques.

What are some of the constraints to initiating a genetic improvement project? First, the factors limiting the efficacy of the natural enemy must be identified. This means that a great deal must be known about its biology, ecology, and behavior. This first step is extremely crucial, as improper identification of the trait needing improvement could lead to an expensive and time-consuming project of little practical value. Second, if using artificial selection, genetic variability must be available upon which one can select. If such variability does not occur in natural populations, it must be provided for through mutagenesis or, perhaps, through rDNA methods. Third, the "improved" natural enemy must demonstrated to be effective in the field.

Recombinant DNA technology offers the potential that genetic manipulation could become more efficient, more targeted, and more creative; beneficial genes isolated from one species could be transferred to many other species if efficient transformation systems can be identified. This research has a number of steps; desirable genes must be identified, cloned, inserted into natural enemies, be incorporated into their genome, be stable, be expressed in the appropriate tissues at the appropriate time, and be transmitted to the progeny. As with plant breeding using rDNA techniques, too few useful genes suitable for enhancing effectiveness of biological control agents have been identified and cloned at present. However, once the transformed natural enemy strain is produced, it must then be fit and able to perform well in the agricultural systems. To determine this, it will require releasing the natural enemies into the environment. Issues relating to the safety of releasing such natural enemies remain to be resolved. Safety questions will probably focus on three issues:

(1) Whether the transformed natural enemy strain is stable;

(2) Whether the improved strain retains its host/prey specificity; and

(3) Whether the ecological range of the transformed strain has been altered.

It will be important to remember that genetic improvement of natural enemies of pests will be initiated because there is a serious pest problem. Risks and benefits of such genetic manipulation projects should be evaluated in terms of the costs and benefits of not doing the project.

Combining Biological Control With Other Agricultural Practices

In practice, effective biological control will often require that several tactics are combined to achieve effective pest management. Thus, once an exotic natural enemy is established, it will probably require specific efforts to conserve it. Alternatively, it may need to be released periodically if it is unable to persist in sufficient numbers (for example, it may be unable to overwinter successfully). In some cases, biological control will provide only partial control and cultural or other *compatible* controls will be needed. Classical, augmentation, and conservation tactics should not be considered to be mutually exclusive. New technologies also should be examined to determine whether they are compatible with biological control and can contribute to improved biological control.

The selective use of pesticides remains a particularly important issue. Biological control agents are often highly sensitive to pesticide applications and increased efforts to use pesticides in a manner compatible with biological control agents could yield relatively rapid and substantial improvements in pest control without requiring new technologies.

Another impediment that limits adoption of biological control appears to be the concept that it must be simple, cheap, and perpetual. Because the Vedalia beetle provided dramatic, complete, inexpensive, and permanent biological control of the cottony cushion scale in California citrus, we tend to use this model in examining potential candidates for biological control. This is unfortunate, for it is likely that we will have to use a variety of tactics in combination to achieve effective control of many pests.

Justifications for Enhanced Funding of Biological Control

Can we justify more funding for biological control? An essential consideration is that our society must recognize the economic, social and health-related long range costs and consequences of present agricultural crop and animal production systems and their practices. We can no longer avoid an assessment of the true costs of inadequate support for agricultural research. Proponents of biological control must emphasize that the actual costs associated with many current pest control practices, including the environmental and social costs, are very high indeed, and that the costs of biological control, even considering its associated risks, are by comparison lower. Such enhanced funding is needed over a long term.

What is Long-Term Support in Biological Control?

Research needs are so great that enhanced funding should be considered as necessary for the foreseeable future. Long term funding is necessary because some ecological studies may require 10 years or more to provide answers. Importation and evaluation of exotic natural enemies in classical biological control programs often takes 5–10 years for each target pest and it is difficult or impossible to speed up these projects, particularly when the target pest has only one generation a year.

22-829 - 89 - 2

While Increased Funding for Biological Control is Necessary, Funding Alone May Not Be Sufficient

Priorities should be redefined. Figure 1 represents a schematic generalization of the *current* interrelationships between elements of an agricultural production system. The current emphasis seems to be on counting and controlling pests, with chemical control the primary tactic employed. The negative effects of chemical control on biological control, the environment, public health, and, to a lesser degree, to the crop plant, are well documented. Currently, many potential cultural practices are underexploited; biorational control techniques are rarely employed.

In Figure 2, following a reprioritization of pest management strategies, the *potential* interrelationships between elements of an agricultural ecosystem are shown. *Notable differences are illustrated in the priorities given to enhancing the use of cultural controls, plant resistance, biorational controls, and biological controls, all of which can be compatible.* The role of chemical control has been dramatically reduced, although it need not be eliminated if it can be used in a manner compatible with biological controls.

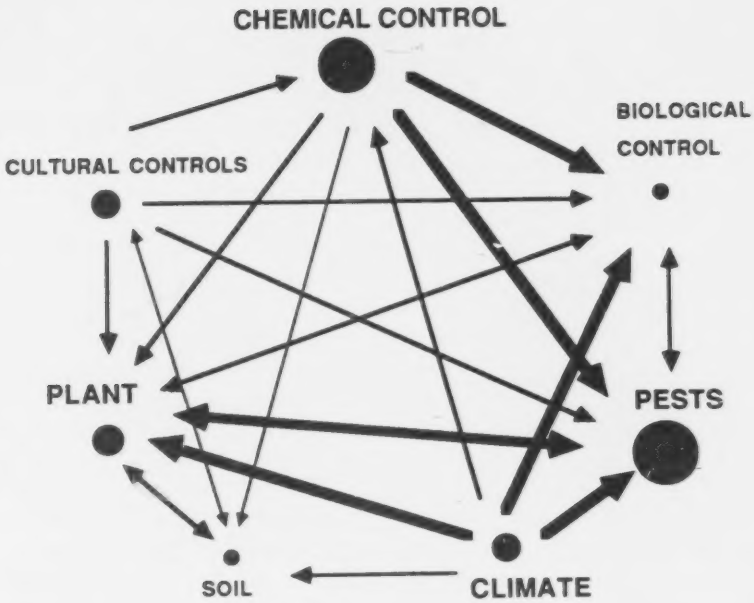


Fig. 1. CURRENT INTERRELATIONSHIPS BETWEEN ELEMENTS OF AN AGRICULTURAL ECOSYSTEM

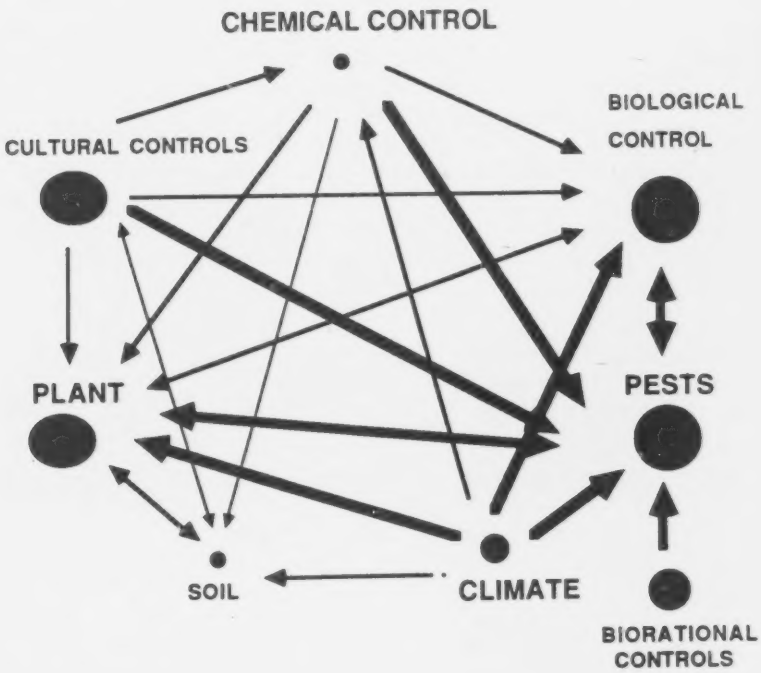


Fig. 2. POTENTIAL INTERRELATIONSHIPS BETWEEN ELEMENTS OF AN AGRICULTURAL ECOSYSTEM

Recommendations

(1) Biological control must receive additional resources and attention. Resources should be committed on a permanent basis to improving biological pest control in agriculture.

(2) A national committee should be organized to prioritize and coordinate classical biological control efforts. Because there is no formal organization to coordinate efforts in classical biological control among university scientists, governmental agencies, and industry, efforts have been limited and uncoordinated. By coordinating efforts, duplication can be reduced, cooperation can be fostered, and important problems can receive a focus.

(3) Adequate quarantine facilities are lacking to process natural enemies for classical biological control programs. Federal funds should be made available to develop several new regional cooperative State quarantine facilities to deal with pests having a regional impact. These quarantine facilities should be administered by University scientists.

(4) A major national competitive grants program in biological control should be developed to obtain the basic information on pests and their natural enemies. The research should include fundamental studies on biology, ecology, systematics, biochemistry, and behavior of natural enemies. Research should be quantitative and interdisciplinary in nature; it must concentrate on mechanisms; it must span the basic to the applied, and it must involve both field and laboratory approaches.

(5) Enhanced education and communication efforts are necessary if the new information obtained from the competitive grants program is to be implemented in United States agriculture. Effective use of biological control in agriculture requires four components: (a) research, (b) development, (c) delivery and education, and (d) evaluation. Implementation of biological control in agriculture cannot be achieved without strong efforts in all four areas. Components b, c, and d are often viewed as the perview of Cooperative Extension in the States. Transfer of research information obtained by Experiment Station scientists to Cooperative Extension personnel is difficult and inefficient under the current organizational system. Funding of implementation and evaluation phases of biological control should be enhanced.

(6) Biological control specialists should be included when initiating IPM or LISA projects so that biological control can have a central role in their design.

(7) Because pesticides can disrupt the biological control of many nontarget pests, the Environmental Protection Agency should develop additional requirements for information when registering pesticides. Ideally, the label for each pesticide should include specific information on the relative toxicity of the product to specific biological control agents in each crop for which the product is registered. The EPA will need to solicit the input of both industry and University scientists in order to achieve a balanced and realistic set of guidelines.

Additional Recommended Reading

ESCOP Working Group on Biological Control. 1989. *Biological Control—An Untapped Natural Resource,* 8 pp., Agric. Commun. Services, Agric. Exper. Station, Purdue Univ., West Lafayette, Indiana 47907.

Biological Control in Agricultural IPM Systems, 1985, M.A. Hoy and D.C. Herzog, editors, Academic Press, 589 pp.

Exotic Plant Pests and North American Agriculture, 1983, C.L. Wilson and C.L. Graham, Academic Press, 522 pp.

THE INTEGRATED PEST MANAGEMENT EXPERIENCE

(By George W. Bird, Nematologist, Michigan State University, East Lansing, MI)

Integrated pest management (IPM) consists of the design, use, and continued evaluation of pest control procedures that result in favorable socioeconomic and environmental consequences. In a 1979 Presidential Message to Congress, IPM was defined as *"A systems approach to reduce pest damage to tolerable levels through a variety of techniques, including predators and parasites, genetically resistant hosts, natural environmental modifications, and when necessary and appropriate, chemical pesticides."*

History of Pest Management

Since the beginning of society, humans have competed with pests for essential natural resources. On occasions, activities of pests have caused famine or vectored pathogens of major disease epidemics. Pests represent a potential risk to our quality of life, and humans have always searched for ways to lower their detrimental impacts to an acceptable level. Historically, many types of pest management procedures have been tried with various degrees of success.

The general nature of pests was reasonably well understood by the second decade of the twentieth century. For some situations, biological, cultural, chemical, physical, genetic, and regulatory pest control procedures were available, and there was a rapid increase in the use of oils and inorganic chemicals as pesticides. By the mid 1930's, however, a limited number of scientists had observed development of pest resistance to pesticides, and realized that frequent and broad scale use of chemical controls was not a long-term solution to the challenges of pest management.

Research activities associated with World War II lead to the discovery, development, and common use of synthetic organic pesticides. The number of available chemicals increased rapidly, and it appeared to most scientists, private business representatives and the public that the age-old problems of pest management would be permanently resolved through chemotechnology. There was, however, a small group of ecologically oriented scientists with a different point of view. This minority opinion was founded on an understanding of the role of pests as important components of food chains, pest population dynamics, and the carrying capacities of our natural resources.

The potential risks associated with the use of pesticides were identified by Rachel Carson in 1962, in her book, *Silent Spring.* Today, it is known that the unexpected consequences of the chemotechnology revolution include:

- Development of pest resistance to pesticides.
- Chemical contamination of the environment.
- Acute and chronic human health risks.
- Harm to non-target beneficial organisms.
- Pesticide-induced evolution of new key pests.
- Pest population density resurgence.

In 1972, the U.S. Council on Environmental Quality published results of a study entitled, "Integrated Pest Management." The report stimulated local, State, national and international interest in IPM. 1972 was also the year that the Federal Insecticide, Fungicide and Rodenticide Act of 1947 was amended to create a comprehensive structure for the regulation of pesticides. This awareness resulted in the partial development and adoption of integrated pest management (IPM).

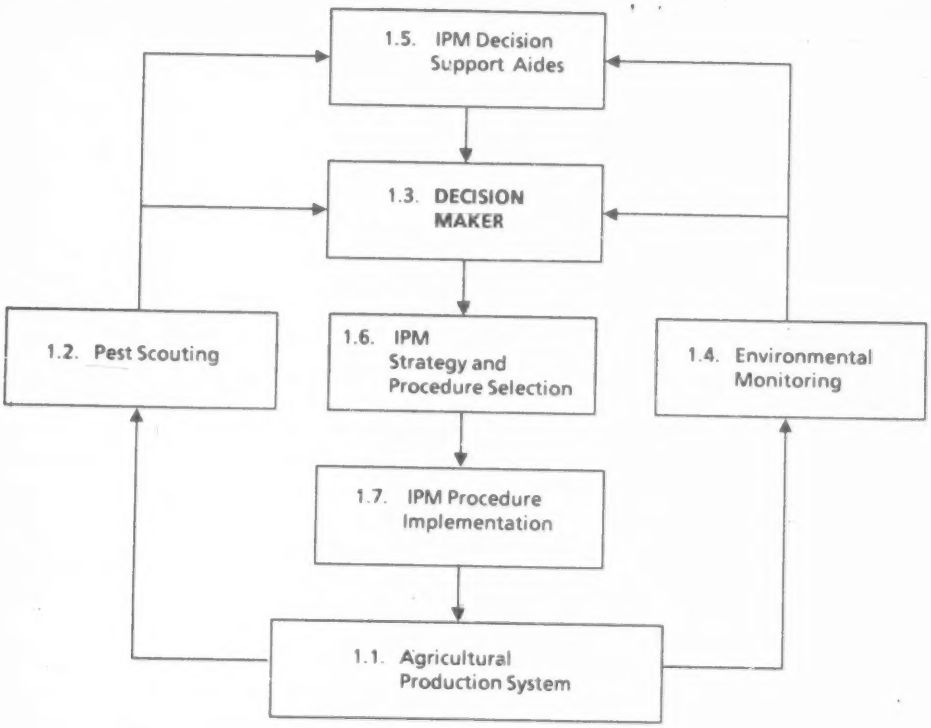

1.5. IPM Decision Support Aides
1.3. DECISION MAKER
1.2. Pest Scouting
1.6. IPM Strategy and Procedure Selection
1.4. Environmental Monitoring
1.7. IPM Procedure Implementation
1.1. Agricultural Production System

Figure 1. Conceptual model of the components and process of IPM (Integrated Pest Management).

The Process of IPM

Although the evolution and utilization of IPM is far from complete, IPM can be described as a process having seven components (Fig. 1). The production system is the focal point, or most important component of agricultural IPM (Fig. 1.1). Biological monitoring (Fig. 1.2) is frequently referred to as scouting. Biological monitoring

consists of sampling procedures designed to estimate the stages and population densities of specific pests and beneficial organisms. It also involves monitoring the stage of development and symptomatology of the associated agricultural commodity. IPM is a knowledge intensive procedure, and requires a highly trained scout. The agricultural production system manager or decision maker (Fig. 1.3) is the second most important component of IPM. This is the individual responsible for the profitability and environmental quality of the system, and is hypothetically the individual best suited for extensive expertise in IPM. In reality, however, private or public sector scouts or private consulting firms are usually hired to conduct biological monitoring.

Pest populations and the growth and development of crops are governed by environmental parameters such as air temperature, soil temperature, soil moisture, light intensity and relative humidity. Weather monitoring information for IPM must be available on both a regional and local basis (Fig. 1.4). This information must be readily available, user friendly, and as close to real-time as possible. Weather monitoring systems for use in IPM programs have improved greatly during the past decade. In addition to macroclimatological information, firm-level microclimatological data is frequently imperative for predicting diseases caused by fungi and bacteria. Dedicated microcomputers are currently available for use in environmental monitoring in a significant number of agricultural systems.

Because of the complexity and the large number of potentially significant interactions between pests, beneficial organisms, crops, agricultural animals and the environment, decision support aides can be important aspects of IPM systems (Fig. 1.5). These may be relatively simple look-up tables, or computer software. A decision support system may be based on simulation models from research data, or developed as an expert system. A few decision support aides have incorporated elementary aspects of artificial intelligence.

The agricultural production system manager or designated representative is responsible for pest management decisions (Fig. 1.3). This aspect of IPM is an extremely knowledge intensive process. An individual within the specific production enterprise may be assigned the IPM decisionmaking responsibility, or a private consultant can be hired for this activity. Individuals trained only in pest scouting must never be delegated the responsibility of IPM strategy or tactic decisionmaking. The basis of IPM decisionmaking is the threshold concept. The first threshold that needs to be considered is the action threshold (Fig. 2). When the population density of a pest reaches an action threshold, or is predicted to reach this level in the near future, it is time to select appropriate IPM strategies and tactics for implementation (Fig. 1.6).

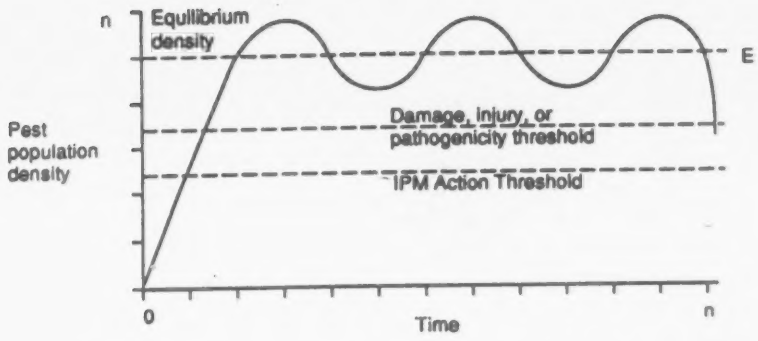


Figure 2. Relationships between pest population density, equilibrium density, damage threshold and action threshold.

The economic threshold must be estimated when selecting IPM procedures. IPM procedures should usually be implemented when the marginal revenue derived from the management input is equal to the marginal cost of the management procedure. The economic threshold is a dynamic concept and depends on the cost and efficacy of the pest management input, production system economics, nature of the pest and its population density, and environmental quality considerations. Although IPM strives to reduce environmental and human health risks, the costs associated with these externalities are not usually available for incorporation into the economic threshold. Where the conditions of the economic threshold exist, an appropriate pest management procedure should be implemented (Fig. 1.7). This will usually consist of manipulation of the pest, crop or animal, or through regulation of their associated interactions.

After implementing an IPM procedure, it is necessary to continue the biological and environmental monitoring to determine if the desired pest management objectives were achieved, or if there is need for additional action (Figs. 1.2 and 1.4). IPM has been successfully implemented in a number of important agricultural systems. Although institutional, educational, and social constraints of the past decade have slowed its development, IPM has become a well established concept. The principles of IPM are ideally suited for use in the pest management components of future systems of sustainable agriculture. Although the brief overview of the process of IPM used examples from agriculture, the philosophy and procedures of IPM are suitable for the management of pests associated with forest and aquatic production systems, and human living environments.

Current State of IPM

During the past two decades there have been a number of federally sponsored IPM research efforts in the USA (see list of Selected References). These include the Huffaker Project, a 15 University Consortium for IPM Research (CIPM), and a similar Consortium for International Crop Protection (CICP) sponsored by USAID.

Starting in 1972, the USDA Extension Service provided resources for pilot IPM programs, and in 1977 funding was made available to all States. Between 1977 and 1979 several national IPM reports and policy initiatives were published. Volume 30 (October, 1980) of BioScience was dedicated to the topic of IPM. As a result of the 1979 USDA IPM Coordination Report, four regional IPM research projects were initiated and regional research funding became available on a competitive grant basis in 1984. A number of States such as California, Wisconsin, and New York have provided significant State appropriations for IPM research, extension, and teaching. Others, such as Michigan, have recognized the significance of IPM, but have not made a specific formal fiscal commitment to this activity.

In 1988, the National IPM Coordinating Committee published a brief summary of the current state of IPM in the USA, and a national IPM workshop was held during the spring of 1989. The current national IPM research program is funded annually at $3 million from the Special Grants Section of PL 89-106. Since 1984, IPM research resources have been made available through a regional peer review process to 177 scientists at 44 institutions. Funded research includes projects in the areas of biological monitoring, epidemiology, pest ecology, pest-crop interaction, innovative management tactics; and IPM technology development, maintenance and delivery. The 1988 report states that the research goal for IPM should be "to assimilate the knowledge developed in basic, monitoring and tactics development research into a total, integrated pest management system. The system is based on sound ecological principles, the numerous interactions between management tactics within and between crop production disciplines, and the numerous interactions within production management" (Table 1). The report also indicates that there is an urgent and continuing need for expanded research, technology development, facilitation, persuasion, and education in the area of IPM. It is also stressed that IPM is closely allied with emerging technologies such as biotechnology, sustainable agriculture, water quality, genetic improvement of plants, farming management systems, urban agriculture environmental quality and energy efficiency.

TABLE 1.—COMPONENTS OF AN INTEGRATED PEST MANAGEMENT RESEARCH SYSTEM—INTEGRATED PEST MANAGEMENT SYSTEMS

Basic research	Tactics and monitoring development research	Integrated systems and management research
Molecular biology	Movement and dispersal of biotic agents	Systems level I.[1]
Biotechnology	Pesticide resistance management	Systems level II.[2]
Biological stress	Pesticides	Decision support systems.
Pest science	Biological control	Expert systems.
	Host plant resistance.	
	Cultural practices.	
	Crop loss assessment.	
	Biological impact assessment.	

[1] Integration of tactics and monitoring components into strategies to control a single pest.
[2] Integration of tactics and monitoring components with strategies to control multiple pests on a single commodity or cropping system.
Source: From National IPM Coordinating Committee Report, 1988, p. 6.

The philosophy of IPM has been successfully diffused into many pest management programs. In agriculture, IPM is usually implemented by individual growers with the assistance of scouts or private consultants. Frequently, however, only a portion of available IPM technology is implemented on an individual farm.

Role of IPM in Sustainable Agriculture

The nature of pest management in future sustainable agricultural systems is not well defined. It is highly likely, however, that the major pest management strategy in sustainable agriculture will be pest problem avoidance through system design. The pest management objective will be to exclude pests (including major pests of current commercial agriculture) from the area of concern, and maintain pest populations at population densities below the damage/injury/pathogenicity threshold. For a pest management component of a sustainable system to be successful, the pest management objective must be achieved at least 4 of every 5 years (Fig. 3). This will mandate the use of system design as a management procedure. Because of the dynamics of pest populations, there may be years when appropriate short-term pest control tactics will be necessary to redirect the population dynamics of a pest and its associated natural control factors. Moving toward a more sustainable agriculture will require the closure of energy conversion, soil, air, and water cycles, and waste that have been broken or altered during the past 50 years of major dependence on the tactics of chemotechnology (Fig. 4).

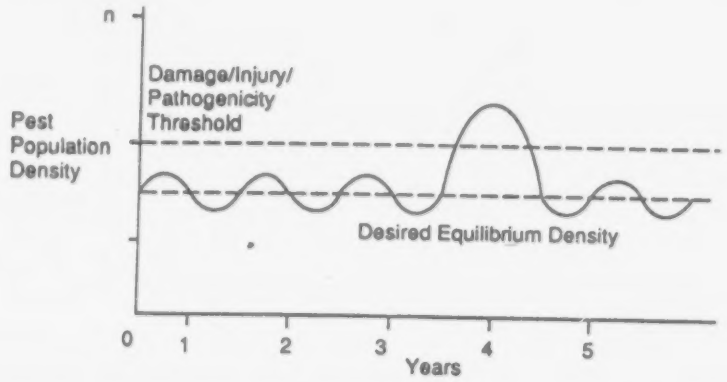


Figure 3. Population dynamics of a potentially major pest in a sustainable agricultural system in which the population density is maintained below the damage/injury/pathogenicity threshold in four of five years.

During the evolution of IPM, a number of important lessons were learned. It should be possible for sustainable agriculture to avoid many of the mistakes made during the early development of IPM. The following is a check list of considerations that should be reviewed frequently during the development of sustainable agriculture programs.

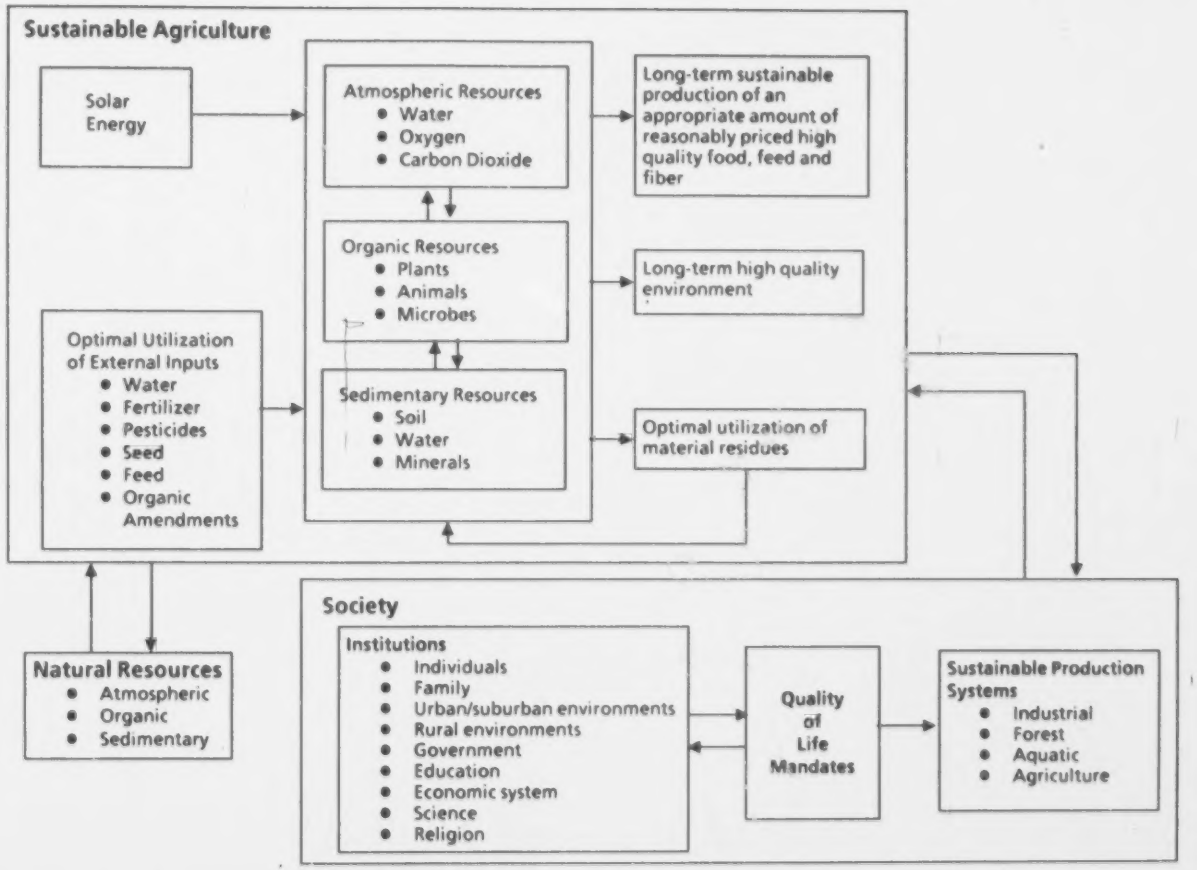


Figure 4. Conceptual model of sustainable agriculture in relation to society and natural resources.

• Do not get into an adversarial relationship with existing institutions.

• In some circles IPM was initially sold as a replacement for pesticides. This created an adversarial relationship between IPM and the pesticide industry that setback IPM as much as 10 years. This issue has been resolved, and the adversarial relationship does not exist today.

• Involve the fertilizer industry in the design, development and implementation of sustainable agriculture.

• Involve mainstream commercial agriculture in the design, development and implementation of sustainable agriculture.

• Maintain a good relationship with the original innovators of sustainable agriculture.

• Pay appropriate respect to IPM in its pioneer role in relation to the evolution of sustainable agriculture.

• Do not oversell sustainable agriculture.

• There is often a very fine line between overselling or underselling a technology.

• Never attempt to implement a sustainable agriculture program before it is ready for adoption.

• This must involve an appropriate system of α and β testing.

• Premature attempts at diffusion of innovations can result in major delays in adoption.

• Make sustainable agriculture programs in academia interdisciplinary.

• For an interdisciplinary program to work it must have the proper mix of professional expertise (but the personalities must be able to work in a truly interdisciplinary arena).

• The necessary resources must be available, and long-term firm administration support is imperative.

• Use of the principles of systems science may be necessary.

• Require an appropriate blend of research (basic and applied), technology development and diffusion of innovation procedure.

Prognosis and Recommendations

On December 4, 1987, a Governor's Conference on "Pesticides, Benefits, Risks and Alternatives" was held at the Michigan State University, Kellogg Center. Dr. J.B. Kendrick, Jr., Vice President of Agriculture and Natural Resources Emeritus presented an outstanding talk entitled, "An Overview of Integrated Pest Management". In this presentation, Dr. Kendrick stated:

"I would like to spend a few minutes assessing the apparent status of IPM programs. Aside from a few successes, I believe we have generally fallen far short of our optimistic expectations and promises. Most of our major crops are still subjected to traditional pest control measures and urban pest and disease management is in its infancy. Why is this the case, when a quarter of a century has elapsed since Rachel Carson called our attention to the hazards of pesticide accumulation in our environment?

"Without intending to occur excuses for the slow development and implementation of IPM, I have concluded that there are a number of reasons for the present embryonic state of IPM. First, we must recognize that throughout the history of plant pest and

disease control, control philosophies have been based on the assumption that the farmer himself would apply the treatment(s) routinely in his overall farming practices. This treatment philosophy is to be contrasted with the professional treatment of human and animal diseases and disorders generally. Admittedly, there Is a certain level of nonprofessional treatment involved in human and animal cases also, but certainly not to the extent found in plant culture, and then only in cases of relatively minor seriousness. This concept of self-treatment in plant culture is deeply embedded in our traditional agricultural practices, and in my judgment, it is one of the major factors in slowing the widespread adoption of IPM strategies for pest control. Let me elaborate.

"1. IPM strategies are often slow to achieve an acceptable level of pest control in contrast to the action of a pesticide which is lethal to the target pest. The IPM strategy may call for no action at all, which is counter to what has been the conventional wisdom of farmers.

"2. The results of using IPM strategies are not immediately visible or apparent as is the 'body count' or targeted pests which have been successfully killed by effective chemical pesticides.

"3. There is a natural and understandable reluctance to risk the potential for failure in employing a new practice of pest control which may call for doing nothing during the early stages of pest and disease observance on the crop-host of particular interest to its owner or manager.

"4. The IPM system of pest and disease control is complex and difficult to understand and apply without special training.

"5. Reliable and comprehensive information on which to base integrated pest management strategies is slow to develop.

"6. Data accumulation on which IPM systems' development must be based is often dull, tedious and lacking in academic challenges and creativity.

"7. It follows then that adequate recognition and reward for academic participation in the developmental stages of IPM systems are not commensurate with the time and effort expended. There is, therefore, a deficiency in academic participation.

"8. There is a lack of adequate private sector opportunities for IPM practitioners and specialists.

"9. It therefore follows that student interest in training for careers as private practitioners of IPM or more broadly as crop management specialists is low or absent.

"10. And to complete this 'Catch-22' situation, the lack of student interest creates a deficiency of adequately trained private practitioners who could be expected not only to promote the concept of IPM, but to demonstrate its value by managing the pest control needs of farmers and urban land managers.

"11. Finally, there is a lack of significant and sustained financial commitment to IPM program development and implementation."

Change is imperative for U.S. agriculture to remain competitive in both world and domestic markets. Some commercial agriculture enterprises will enlarge, while the size of other production units may remain constant. In both cases, however, the nature of the technology used in agriculture will change, and economically viable agriculture will become more like other types of human-managed

production systems. The technology of pest management will become much more sophisticated and require the services of private sector professional plant and environmental health specialists.

The profession of plant and environmental health will resemble its counterpart of Veterinary Medicine. A new professional degree identified as a Doctorate of Plant Health (DPH) will be required. This concept was originally proposed by Dr. J. Artie Browning in Congressional Testimony, and in his 1983 Presidential Address to the American Phytopathological Society. It is my belief that until strong professional degree programs such as a Master of Science in Integrated Pest Management, and Doctorate of Plant and Environmental Health Degrees become a reality, broad scale implementation of many of the potentials of IPM will not be possible. Conversely, the pest management professions will not evolve until there is a significant demand. The necessary planning for this change can be fostered through education, facilitation and persuasion efforts. Recent developments such as the 1989 alar and aldicarb crises indicate that the time (possibly, 1935–1990) for planned change for diffusion of innovations may be nearing an end, and we could be entering a period of rapid change dictated by perceived or real crises. In either case, it is time to develop one National and four Regional Centers for Plant and Environmental Health. These institutions would employ research, teaching, and clinical faculty, and would grant degrees in the areas of IPM, Environmental Science, and Plant Health. They would also be excellent institutions for appropriate integration of the emerging activities in the areas of biotechnology and sustainable agriculture. This proposal does not duplicate the current activities of existing institutions, I hope, however, that at least the four proposed Regional Plant and Environmental Health Centers will be located at land-grant institutions. This is imperative to take advantage of existing academic, research and public service programs in the basic, natural resources and production system sciences. A national imperative in the area of Plant and Environmental Health would be a highly significant contribution to the sustainability of the USA's role in global leadership.

Selected References

Adkisson, P.L., R.E. Frisbie, and S.A. Joiner. 1988. A list of publications issued by the Consortium for Integrated Pest Management: 1979–1987. Texas A&M Univ., College Station. 135 pp.

BioScience. 1980. Special Issue: Integrated Pest Management. Volume 30, No. 10.

Burn, A.J., T.H. Coaker, and P.C. Jepson. 1987. Integrated Pest Management. Academic Press, N.Y. 474 pp.

Council on Environmental Quality, Office of the President. 1979. Integrated Pest Management Policy Initiatives. Washington, D.C. 120 pp.

Council on Environmental Quality, Office of the President. 1972. Integrated Pest Management. Washington, D.C. 41 pp.

Extension Committee on Organization and Policy. 1978. Integrated Pest Management Programs for the State Cooperative Extension Services. USDA SEA FE. 21 pp.

Flint, M.L. and R. vanden Bosch. 1981. Introduction to Integrated Pest Management. Plenum Press, NY. 240 pp.

Intersociety Consortium for Plant Protection. 1979. Integrated Pest Management: A Program of Research for the State Agricultural Experiment Stations and the Colleges of 1890. Prepared for the Experiment Station Committee on Organization and Policy. 190 pp.

National IPM Coordinating Committee. 1988. Integrated Pest Management: A National Plan for Future Direction. USDA. CSRS. Washington, D.C. 8 pp.

Office of Technology Assessment, Congress of the United States. 1979. Pest Management Strategies in Crop Protection. Vols. I & II. Washington, D.C.

Pedigo, L. 1989. Entomology and Pest Management. Macmillan Pub. Co. 646 pp.

President's Environmental Message to the U.S. Congress. 1979. August. Washington, D.C.

President's Environmental Message to the U.S. Congress. 1977. May. Washington, D.C.

Resident Instruction Committee on Organization and Policy. 1979. Status of planning and development of educational programs for systems of pest management and plant protection. USDA SEA, Washington, D.C. 5 pp.

United States Department of Agriculture. 1979. Integrated Pest Management Programs. SEA IPM Coordination Report. Washington, D.C.

United States Department of Agriculture. 1977. Policy Statement on IPM. Secretary's Memorandum No. 1929. Washington, D.C.

THE LISA PROGRAM AND THE ROLE OF THE LAND-GRANT UNIVERSITIES

(By Brian F. Chabot, Acting Director, Cornell Agricultural Experiment Station, Cornell University, Ithaca, N.Y.)

The LISA Program (Low Input/Sustainable Agriculture) has unique importance among USDA programs. Not only should it be authorized as a part of the 1990 farm bill, but Congress may well consider it as a model for structuring other research-extension programs in agriculture. In this document I will describe the LISA Program as it exists today, argue for its continuation, and recommend some changes in the authorizing legislation.

Definitions

Because "low input" and "sustainable" are variously defined, I will state my preferences. **Sustainable agriculture** is an encompassing concept which broadens the frame of reference for evaluating agricultural technologies. In addition to the necessary emphasis on profitability, sustainable means longer time horizons and broader consideration of environmental, social and policy dimensions. Low-input, organic, regenerative and ecological agriculture are concepts associated with sustainable, but generally have a more limited range of application. **Low input agriculture** seeks to reduce the use of purchased inputs, while maintaining or increasing yields and farm profits. The objective for reducing the use of purchased inputs is to reduce costs, environmental and health hazards, and natural resource degradation.

LISA and Profitability

The uniqueness of the LISA Program rests on its structure and its orientation. Among those programs authorized within the past decade, it is the only program to directly address the needs of farmers at a practical, immediate, whole farm level. Other programs are oriented toward single issues (e.g. IPM, water quality, biotechnology), toward basic research with distant payoff (e.g. biotechnology, competitive grants program), or toward off-farm problems (e.g. water quality). While these other programs have a valuable role to play, there is a need to address real, immediate problems of farming in an holistic way. The LISA Program fills this role.

The LISA Program came into being at a time of heightened concern about the financial viability of farming and about the long term environmental consequences of contemporary farming practices. The farm financial "crisis" has passed from national attention. However, the long term trends of a declining farm population have not been reversed. Farmers are still going out of business. The underlaying problems are financial, with roots in international

competition, politics, and changing land values. They have real impact on real people. The LISA Program proposed the very simple notion that by controlling costs, using careful management and new technologies, profits and opportunities can increase. In the past 2 years we have had ample testimony and experience from farmers that this simple notion really works! *Even at this point LISA is the only new Federal initiative addressing the farm financial situation.* It is doing so not by regulation or subsidy, but by creating positive, constructive options.

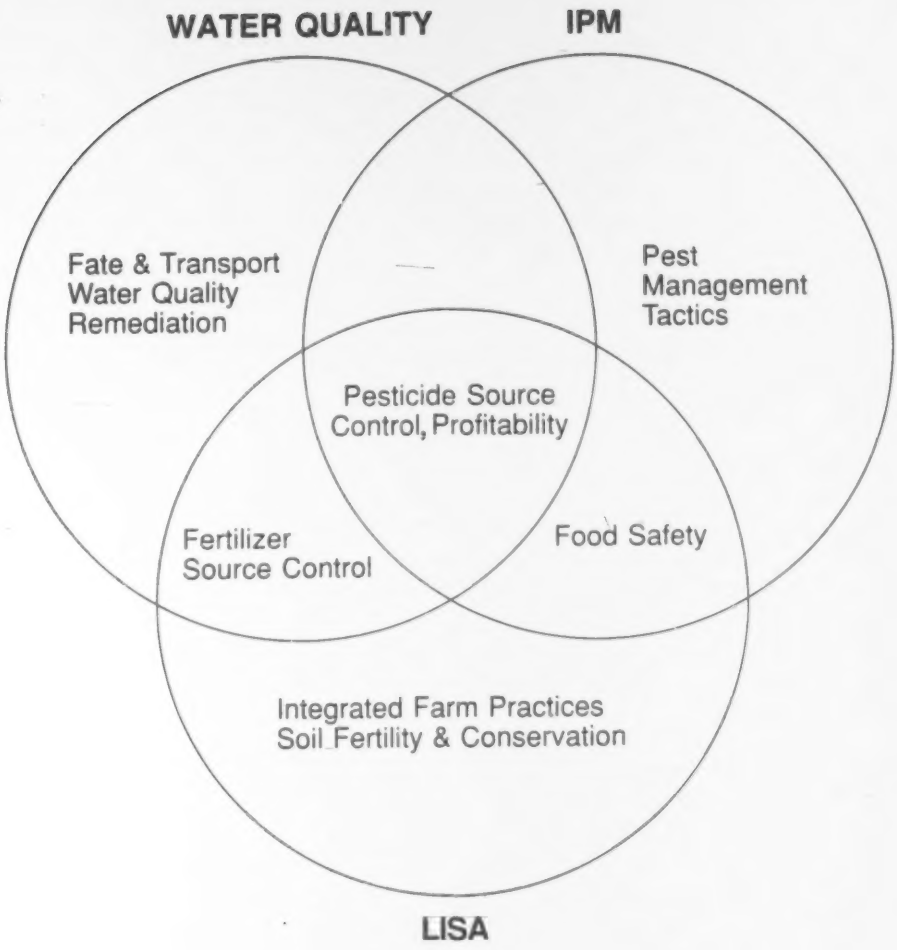
Pesticides

The LISA Program also seeks solutions to concerns about pesticides in the environment and on food. Public concern about pesticides continues to be a major force affecting agricultural practices. Denmark, Sweden, and Holland are proposing a 50 percent reduction in pesticide use as national goals. It is but a matter of time before similar legislation is introduced in the United States.

We know with certainty that there are ways to grow crops profitably on a commercial scale using technologies that substantially reduce the need for pesticides. IPM programs have achieved significant pesticide reductions for a few crops. Demonstration also comes from a large group of farmers who have pioneered techniques of organic, regenerative, and sustainable approaches to farming. They have done this largely on their own, with very limited assistance from Federal agencies, State departments of agriculture, land-grant universities, or the extension service. Land-grant universities and ARS scientists are in the embarrassing position of having to play catch up. Fortunately, there is a substantial group of individuals with the land-grant universities, ARS, Extension Service, and Soil Conservation Service who are interested in contributing to sustainable agriculture through the LISA Program.

Relationship to IPM and Water Quality

LISA is only one of several national programs directed at reducing the use of pesticides. Figure 1 illustrates the relationship between LISA, IPM, and the Water Quality Initiative. Integrated Pest Management (IPM), funded modestly about 10 years ago, has been making the major contribution to altering pest management practices. While its accomplishments are important, funding levels have been insufficient. There are abundant opportunities to expand the effectiveness of this program in meeting rising public expectations.



Research and Extension Relationships
Between IPM, LISA, Water Quality Programs

IPM and LISA will contribute to the Water Quality Initiative by providing technologies to reduce pesticide and fertilizer use that is essential to protecting and improving water supplies. This is the "source control" component of the Water Quality Initiative. The major new programs added by the Water Quality Initiative involve fate and transport studies and remediation of contaminated water supplies. Understanding the processes by which pesticides and fertilizers move to ground water will be important to designing new pest and fertility management systems. An example of the conflicting values can be seen with no-till practices. No-till, while advantageous for soil erosion control, permits the development of root channels and worm holes which greatly accelerate the movement of chemicals to ground water. Remedial programs are important since there are water supplies which have become contaminated from farm chemicals, especially fertilizers, including manures.

LISA as a Catalyst

Congress and OMB have correctly asked what existing Federal moneys were being directed toward LISA objectives. While the figures of $101 million which USDA produced were judged by many to be inflated, it is clear that the primary LISA objectives of profitability, environmental quality, and food safety were receiving attention by existing Federal programs. However, there was also widespread agreement that the job was not getting done. A major advantage of instituting a program such as LISA, in addition to new financial resources, is to provide a rallying point for coordinating efforts which may be scattered or directed at other goals. This has been an early success for the program. In only its second year, Dr. J. Patrick Jordan, CSRS Administrator, described LISA as the most visible of the USDA programs. The openness of the program quickly developed a broad constituency drawing State and private resources to the effort. Land-grant universities have been advertising their involvement in the program. Several national and international conferences have been sponsored with outstanding attendance. A number of States have established their own programs with State funding to match the Federal initiative. The rapid acceptance and response attest to the timeliness of LISA.

I have been overwhelmed with the response to this program. People in research and extension have come forward enthusiastically to say that they do have information and new ideas that can save farmers dollars. Farmer's are volunteering their time, land, equipment, and ideas in support of this program. The non-farming public has been writing to us in unusual numbers to say that this program addresses important concerns for them.

Structure of the LISA Program

The structure of the LISA Program has evolved in the 2 years of its existence. There are four regionally based programs operating under common guidelines. The host institutions serving as administrative centers are the Universities of Vermont, Georgia, Nebraska, and California-Davis. Funds allocated by Congress are distributed through open competition. Anyone in the public or private sector with the capability to contribute to the objectives of the program is

able to be involved. Projects are specifically encouraged that have both research and extension components and direct involvement by farmers. While land-grant universities have played the major role in projects currently underway, there are funded projects operating entirely with private sector organizations and farmers. The objective is to draw out the best ideas wherever they exist. *There is no other program within USDA that is accessible to such a broadly based group of participants.*

Grants are reviewed by a Technical Committee that includes scientists, extension personnel, farmers, and others that has the expertise to evaluate the technical feasibility and value of each proposal. Proposals which make it through this initial evaluation are subject to a second review by the regional Advisory Committee. This group, which also is broadly constituted, makes the final selection based upon considerations of merit, balance, and overall regional needs. Funded projects will have been evaluated by more than 20 people. Based upon the first 2 year's experience, 10–15 percent of proposals submitted are funded. In 1988, 53 projects were funded out of more than 400 submitted. *The review process is rigorous and the program is highly competitive, equivalent to that at NSF or NIH.*

At the Federal level, Congress very wisely mandated that CSRS (Cooperative States Research Service) be the lead agency and that there be close cooperation with other USDA agencies, especially the Extension Service. *Without this particular Congressional guidance the degree of cooperation which presently exists would not have happened.* This candid admission has come from individuals within USDA. Those closely involved feel that the current cooperation is unprecedented and is working very well. Individuals have been designated by CSRS and ES to work together to administer the program. These two individuals meet with regional administrators, technical and advisory committees. Coordination with other USDA agencies occurs through a committee within USDA. ARS and SCS are represented on the regional advisory committees as well.

Two Myths About LISA

"LISA seeks to eliminate the use of pesticides and fertilizers." LISA has established the more realistic target of reducing the use of external purchased inputs in ways consistent with maintaining yields and increasing profits. Centuries of experience have demonstrated that crops benefit from fertilizers and pest control. Today farming in the U.S. has become dependent on industrially synthesized fertilizers and pesticides. It is unrealistic to think that this situation will change radically soon. In many instances commercial pesticides represent the best, most cost effective, or only means for growing a successful crop. This is especially the case since most university and Federal research has focused on optimizing the use of these inputs.

LISA researchers will be exploring the feasibility of technologies that substantially reduce use of industrially synthesized pesticides and fertilizers. They will be trying to discover ways for more dramatic reductions than have occurred to date. While agrichemical manufacturers do find this threatening, it is no less justified than

research programs of the past which have substantially contributed to the profits of these industries. At this point in history, the economics of farming, public health, and environmental quality demands some different approaches. Many of us would prefer to work cooperatively with industry as we move in new directions. New business opportunities are the likely result.

"LISA seeks to turn back the clock to farming practices discarded long ago." Again this is not the intention. Farming practices have changed too much to permit the use of labor intensive practices of the past. The challenge is to find new approaches to achieving our objectives that can be employed in today's farming environment. For example, the challenge in reintroducing rotations for pest control in high value vegetable systems is to find alternative crops that provide sufficient economic returns. In developing pasture-based systems for beef and dairy production we need to reassess how to balance feed supplements to meet current nutritional needs. Some "high tech" solutions, such as computer decision aides, become very useful as management information needs increase. Sustainable agriculture systems useful in today's farm environment will include approaches that are high technology and information-intensive. This is hardly turning back the clock!

What Kind of Projects Are Being Supported?

Projects being funded include some having immediate impact through enhancements in extension of existing information, including compiling information for videos, brochure, fact sheets, and data bases. Critical economic analyses are underway comparing existing high and low input systems. Longer term projects are oriented at fundamental processes which will allow the design of new production practices and systems. A few examples from the 53 projects funded in the first year provide some indication of the breadth of the program.

Immediate impact extension:

- Demonstration of pesticide reduction through use of disease resistant cultivars and IPM for apples in six Northeastern States with a compendium of information on low input apple production techniques.
- Production of on-farm demonstrations, videotape, and fact sheets on using Voisin-managed pastures for dairy cattle and sheep.
- Demonstration of pesticide reduction techniques for apple and peach production in the Southeast.
- Demonstration of reduced cost forage based systems for beef production.
- Implementation of computer-based decision support systems for grapes and apples production management.
- Production of videotapes introducing farmers to low-input practices appropriate for Northeast and Midwest.
- Demonstration of pheromone mating disruption techniques for grape bed moth control.
- Development of farmer networks in Midwest, Southeast, and Northeast to facilitate transfer of low-input practices.

• Development of minimal herbicide weed control recommendations in multi-crop rotations.
• Demonstrations of ridge tillage systems using reduced synthetic pesticides and fertilizers.
• Production of a videotape series on techniques for conversion to sustainable farming practices.
• Development of educational displays illustrating input reduction technologies.
• Development of videos and written material for low input cereal and legume production in the Northwest.

Fundamental research:

• Investigation of nitrogen dynamics in different cropping systems to maximize nitrogen supply and reduce leaching losses.
• Development of a nitrogen management model.
• Practice weed control with living mulch and relay cropping practices.
• Exploration of reduced pesticide practices in ridge-tillage and manure-based cropping.
• Practice use of green manures in northern plains and intermountain region.
• Investigation of solarization as a replacement for soil fumigation.
• Practice use of legumes during fallow period in wheat production.
• Development of economic analyses of low-input practices for Midwest and Southeast small grain and row crop production, for crop-livestock systems, and for vegetable and small fruit production.
• Development of comparative analysis of productivity, water, nutrient, and soil characteristics in low and high input vegetable production systems.

Recommendations for the 1990 Farm Bill

• LISA should be reauthorized.
• Language should be broadened to incorporate the current program objectives. These are:
—to increase profitability and competitiveness by reducing costs;
—to reduce environmental and human health impacts of farming, especially with respect to pesticides and fertilizers; and
—to conserve resources, especially soil and energy.
• Current administrative arrangements should be authorized. Specifically:
—CSRS as the lead administrative agency, in cooperation with ES, ARS, SCS and others;
—A National Advisory Committee with broad public and private representation;
—Four regionally-based programs each at a single host institution;
—Each regional program to have an Advisory Committee and a Technical Committee;
—Funds to be allocated through a competitive process; and
—Funding and program participation to be available to any organization (public and private) with demonstrated appropriate competency.

- Open participation by all relevant organizations and individuals should be encouraged.
- Formalized program integration between LISA, IPM, and Water Quality should be encouraged.

SUSTAINABILITY: DRIVING FORCES

CONSUMER DEMAND FOR SUSTAINABLE AGRICULTURE

(By Michael Jacobson, Executive Director, Center for Science in the Public Interest (CSPI) and Dan Howell, Director, Americans for Safe Food Project, CSPI)

I. INTRODUCTION

All across the country, consumers who are concerned about food safety are focusing attention on how their food is produced, and how Federal and State farm policies control those food production decisions. Consider:

• Recently over 130,000 Americans signed a "safe food petition" that cited concern over pesticide and drug residues in food. The petition was addressed not to the Environmental Protection Agency or the Food and Drug Administration, but to the U.S. and State agriculture departments. The petition called not for stronger pesticide regulations, but for efforts to help farmers grow food with fewer chemicals.

• Earlier, in March 1989, representatives of major consumer and environmental groups joined with over 400 farmers, rural advocates, researchers, and farm policymakers at a National Conference on Organic/Sustainable Agriculture Policies in Washington, D.C. A central theme of the conference was the growing support from groups and individuals outside of agriculture for programs and policies that facilitate the adoption of more environmentally sound farming practices.

• From Georgia to Montana, and throughout such Farm Belt States as Illinois, Missouri, and Nebraska, local "safe food" citizen groups have sprung up to encourage supermarkets to carry food produced without, or with minimal use, of pesticides and drugs. Early this year, before food safety began dominating the headlines, a year-long campaign by a local Michigan environmental group, the Ecology Center of Ann Arbor, helped persuade the nation's second largest supermarket chain, Kroger, to begin test-marketing organic produce.

Consumers, driven by deep-rooted concerns over the safety of pesticide and drug residues, are fueling major changes in the marketplace. These changes increase the pressure on American agriculture to adopt production methods that can provide sustainable profits while allowing significant reductions in chemical use. Many State governments, keenly aware of these market forces, have begun efforts to speed up the transition to sustainable farming, devising programs and policies that offer models for similar efforts on a national scale.

II. Even Before Alar, Consumers Were Alarmed About Pesticides

In 1989 the news media discovered pesticides. Following CBS' "60 Minutes" broadcast on the presence in food of potentially dangerous pesticides like Alar and the limitations of Federal regulatory efforts, media coverage seemed to progress through the pesticide alphabet, turning to stories such as alachlor in chickens and aldicarb in potatoes. Increasingly, the media carried stories about efforts to produce food with fewer chemicals: *Newsweek* declared there was a "panic for organic" food grown without any pesticides; and CBS Evening News aired a series on sustainable farming methods that minimized pesticide use.

But consumers' worries over pesticides in food were on the rise even before this year's Alar scare. In a January 1989, survey by the Washington, D.C.-based Food Marketing Institute (FMI), 82 percent of shoppers called pesticide residues on food a "serious health hazard." That represented not only a seven-point increase from shoppers' response to the same question in 1988, but the highest percentage ever recorded for any of the specific food safety concerns surveyed by FMI for the past 6 years.

Another "pre-Alar" survey conducted in November 1988, by Louis Harris and Associates found that 84 percent of Americans would prefer organically grown food. Even more astoundingly, 49 percent said they would pay more for it. Indeed, an earlier 1988 survey by a produce-industry publication, *The Packer,* found that despite the limited availability of alternative foods in the marketplace, nearly one out of five consumers had already altered their food purchases because of pesticides, including buying foods marketed as organic or pesticide-free.

A 1988 University of Georgia study found that two out of three shoppers would be willing to pay at least 5 percent more for produce marketed as pesticide-free. It found that a slight majority would have greater confidence in having produce tested by an independent laboratory to guarantee it as residue-free than in having a growers association confirm that no pesticides were used in growing the produce. The survey also found widespread interest in locally grown food, with 9 out of 10 respondents having purchased produce from a farmers market at least once in the previous year.

Consumers' food safety concerns and interest in buying alternative products extend beyond pesticides to include animal drugs. The above-mentioned 1989 Food Marketing Institute survey also found that 61 percent of shoppers regarded antibiotics and hormones in poultry and livestock as a serious health hazard, a figure unchanged since FMI began asking the question in 1987.

A University of Wyoming study conducted in 1986–87 suggested that the consumer market for natural beef produced without drugs or hormones could be very large. A consumer test in the San Francisco area compared sales of "Wyoming Lean Beef," produced especially for the study, with regular beef available in the supermarket. The Wyoming beef was priced 25 percent higher. Nevertheless, the study found that "30 percent of consumers in the test area [would] pay a premium for its health characteristics even though

marbled beef is more enjoyable to eat." [*Choices*, American Agricultural Economists Association, Second Quarter 1988.]

II. Supermarkets Scramble To Offer Safer Food

Retailers, who know how to read marketing surveys, have responded in a big way to consumers' demand for foods produced with fewer chemicals.

Today, well over 1,000 of the Nation's 17,000 supermarkets test certain foods for pesticide residues, using a private company that certifies the absence of residues of certain pesticides at detection limits much lower than the legal tolerance for the chemicals tested. By their use of private testing, supermarket chains put significant pressure on the growers who sell to them to reduce pesticide use. In fact, the testing firm works with the stores' growers to lower their use of chemicals and adopt sustainable practices.

In addition to certifying that certain produce items have been tested and found free of even fairly low levels of many pesticides, pr te residue testing is also used to screen some produce for the presence of illegal levels of a limited number of pesticides considered more dangerous to human health. Supermarkets can use such "dock screening" programs to develop profiles of certain growers who regularly ship tainted produce, and to direct business toward growers who supply less contaminated food. Prior to the publicity this year over Alar, hundreds of supermarkets in the United States were carrying organically grown produce and other organic foods. While major chains like Kroger and Safeway were conducting test-marketing of organic fruits and vegetables, medium-sized chains like HEB in Texas and Shop & Stop in Massachusetts were carrying organic produce at many or all of their stores.

But the 1989 "panic for organic" has caused the market for foods grown without pesticides to explode. In California, the farm-gate prices for organic produce are expected to hit $100 million this year, double the 1987 figure, according to Dr. Roberta Cook, an agricultural economist at the University of California at Davis. In July, a task force organized by the produce industry held a major national meeting on organic food standards, with one task force member explaining that organics "is not a fad, but a trend."

Spurred by State agriculture departments, many supermarkets have recently begun offering more locally grown fruits and vegetables, which do not need many of the "post-harvest" chemical applications designed to maintain an edible appearance while they are shipped long distances. The 115-store Stop & Shop supermarket chain began carrying sections of locally grown food in its Massachusetts stores in 1988.

Supermarket-sized natural food store chains have emerged as a growing competitive force in several parts of the country. Several chains, including the Texas-based Whole Foods Markets and Boston's Bread & Circus, offer large sections of organically and locally grown foods.

According to the Food Marketing Institute, among those who shy away from certain foods because of safety concerns, consumers avoid red meat more than any other food. Thus it's not surprising that today, over 1,200 supermarkets offer special-label beef pro-

duced without the use of growth hormones and produced so as to minimize fat content.

Finally, when consumers have been unable to buy organic foods or drug-free meats locally, many have taken to ordering organic food by mail. In the past year, the Center for Science in the Public Interest's Americans for Safe Foods Project responded to over 20,000 written requests for its listing of mail-order suppliers.

IV. States Launch New Efforts To Boost Sustainable Agriculture

The rush in the marketplace to meet consumer demand forfoods produced with fewer chemicals has put significant pressure on farmers, who have been flocking to conferences that disseminate information on sustainable production methods.

At the Federal level, the tiny $4.45 million Low-Input Sustainable Agriculture Program has successfully involved farmers in the design of research and information projects, and has produced the kind of practical information farmers need to respond to new market pressures.

But more can and should be done to address not only the need for getting useful information into farmers' hands, but also to help overcome other obstacles to the production and marketing of safer food. To fill the void left by the limited Federal role in this area, State governments have seized the initiative, driven by the desire to help farmers cut costs, and by concerns about the impact of farm chemicals on the environment and on the health of farmers and rural residents. Among the efforts currently underway are the following:

• *Statewide Sustainable Agriculture Programs:* Iowa, California, Texas, Minnesota, and Wisconsin have established statewide research programs to develop and distribute information that farmers can use now on how to adopt profitable, low-input farming methods. Iowa's program is funded in part by taxes and increased registration fees on farm chemicals.

• *Adopting Standards for Organic Food:* 18 States have passed laws or adopted regulations defining "organic" for labeling purposes. Such laws give consumers confidence that food labeled organic actually was organically grown. They also help organic farmers within a State to compete against organic foods produced in States with strong standards.

Five States—Texas, Washington, Minnesota, New Hampshire, and Vermont—either inspect organic farms or provide financial support for programs to certify that organic farms are complying with strict standards.

• *Financing Alternative Agriculture:* If a farmer tells his bank that this year he'd like a loan to start producing organic chickens, he may be told to go to the organic bank. To deal with the problem of helping farmers obtain loans for non-traditional ventures, several States have established programs to provide below-market-interest financing of alternative farming projects. For example, in 1988, Minnesota's legislature appropriated $1 million to fund a sustainable agriculture loan program.

• *Sustainable Agriculture Education:* Many land-grant universities and other State-supported institutions offer college training in sustainable farming methods. At the University of Vermont and University of Maine-Orono, students can earn 4 year degrees in sustainable agriculture. The University of California-Santa Cruz offers a full curriculum through the Ph.D level in agroecology and sustainable agriculture.

• *Marketing Assistance for Organic and Locally Grown Food:* A number of States work aggressively with farmers, food distributors, and retailers to promote the sale of foods grown in-State. Approaches include certification and technical assistance for farmers' markets, persuading supermarket officials to carry sections of locally grown foods and State-certified organic food identified with special State logos, and helping organize associations of farmers' markets and organic growers.

• *Certifying Independent Soil-Testing Labs:* Excessively high fertilizer recommendations from private soil-testing laboratories exacerbate the environmental and health problems caused by fertilizer use. Iowa and Minnesota have established voluntary certification programs for private labs to ensure accurate, reliable recommendations.

The drive for sustainable agriculture has often come from the grass roots. Farmers who practice organic and low-input methods are sharing their knowledge with Extension Service personnel. Farmers and rural advocacy groups are pressing lawmakers for sustainable agriculture programs that farmers will help to run. Organic farmers are drafting and sometimes administering State programs to certify organic farms.

Indeed, many State sustainable farming programs offer potential models for the Federal Government as it considers proposals for expanded research efforts, national organic standards, and related steps. Former Texas Assistant Commissioner of Agriculture, Susan DeMarco, recently wrote in an article describing States' agricultural innovations:

> State leaders have paved the way for experimentation, demonstrating that government can provide services rather than excuses. This rejuvenated spirit of inventiveness ought to be taken to Washington as the first step toward a rational policy for regenerating American agriculture.

V. Specific Proposals Congress Should Consider During the 1990 Farm Bill Deliberations

The Center for Science in the Public Interest, along with farm, environmental, and consumer groups representing millions of Americans, joined as a signer of recommendations prepared by the Institute for Alternative Agriculture which were sent to then President-Elect Bush last December. The groups urged three basic categories of change in Federal farm policy:

(1) Addressing the disincentives against sustainable practices embodied in "current farm commodity programs that encourage monocultural cropping systems and discourage environmentally sound practices";

(2) "More research into practical methods needed to adapt low-input [methods] to the various ecological situations in which our farmers operate,"; and

(3) Expanded efforts to disseminate information about low-input farming methods.

CSPI also encourages Congress to adopt strong, uniform national standards for organic food, drawing from the experience and knowledge within the organic food industry, and preserving a flexible role for the States to administer or authorize certification programs.

As consumers mature in their understanding of the complexity of the food-safety problem, and of the significant difficulties and costs of monitoring and policing farm chemicals after they have been applied, we increasingly view programs that reduce farmers' dependence on chemical inputs as a more efficient and effective long-term response to the food safety problem. Because food safety is just one of several adverse "side effects" of farm chemical use, we should all realize that the forces for change in American agriculture toward safer, more environmentally sound farming are strong, indeed.

DIVERSITY IN CROP PRODUCTION

(By David F. Bezdicek, Professor, Department of Agronomy and Soils, Washington State University, Pullman, WA)

Global Aspects

Diversity has long been associated with stability in most ecosystems. However, disturbances from urbanization, mining, deforestation, industrialization, waste disposal, acid rain and agriculture activities have drastically, and in some cases, irreversibly altered biogeochemical cycles and biological diversity. In some areas, permanent damage has resulted and in others, restoration is only limited.

Today, deforestation of boreal and tropical forests and soil erosion are two of the most serious disturbances associated with human activity. Drought in Northern Africa is a prime example of deforestation where once-productive farmland has been nearly destroyed. In addition to the climatic and sociological changes that result from deforestation, permanent changes often occur in plant communities that adversely affect biological diversity. In addition, changes in the physical and chemical soil environment causes further decline in ecosystem stability which often prevents restoration.

Soil erosion which is often the result of deforestation and agriculture operations can often alter the terrestrial environment to the point that productivity and biological diversity can never be restored. However, in agroecosystems, some restoration of soil carbon and organic matter is possible through proper soil conservation regeneration practices. Since forest and agriculture ecosystems contain 80 percent of the earth's terrestrial carbon, continued disturbances may cause irreversible changes in global carbon cycling and in both terrestrial and microbial diversity.

Historical Changes in Agricultural Diversity

Crop rotations in association with animal enterprises were common place in agriculture for over 9,000 years until synthetic fertilizers began to replace nutrients depleted from the soil and chemicals were used more extensively to control pests, weeds, and pathogens. Through plant breeding, fertilizers, pesticides, and changes in crop management, crop yields increased substantially from the 1940's to the present. Breeding of cereals with shorter and stiffer stems permitted higher yields to be obtained at higher fertilizer rates without lodging. Some will argue that these varieties offer less competition against weeds because of their shorter stature. This westernized type of agriculture is high-energy intensive and relys heavily on external inputs of chemicals and fertilizers.

Furthermore, environmental and food quality concerns and reduced supply and future cost of fossil fuels will impose limits on these inputs which can be replaced in part by more emphasis on biological control and increased diversity through longer crop rotations. More sustainable systems that offer longer term solutions must be adopted over short-term, quick-kill solutions.

Diversity of the cropping system is related to the genetic diversity of the crops, to the mix of crops planted in space or time, and to microbial diversity which is controlled to some extent by the above factors. Environmental factors such as temperature and moisture influence diversity by setting limits on what type of crops can be grown and by the type of soil flora and fauna that result.

It is well known that the greater the complexity of the biological community, the greater its stability. Such a system is well buffered and can resist envasion by other organisms, especially pathogens. On the other hand, agroecosystems of monocultural and short crop rotations containing plants with narrow genetic base are less diverse and consequently more vulnerable to envasion by insects, diseases, nematodes, and weeds. In vast acreages of single crops, epidemics are favored, especially by rusts and other diseases in wheat. A classic example is the potato blight epidemic and famine in Ireland which was caused by an introduced fungus *Phytophthora infestans* on the relatively susceptible potatoes. A more recent example in the United States is the southern corn leaf blight in the 1970's which was caused from the majority of corn hybrids carrying the same factor for male sterility (for use in plant breeding) and susceptibility to the blight. In small farm holdings in the tropics, a multitude of different crops and patterns provides for a maximum of diversity. Although improved varieties are used and are often associated with commercial agriculture, some farmers in developing countries abandon improved varieties because of risk and expense in favor of time-tested, locally adapted stocks. Introduction of more genetic diversity into new plant varieties and cultivars is necessary for greater stability and a goal in plant breeding. Biotechnology may also aid in this process through tissue culture and mapping of plant genes. Greater diversity and resistance to diseases and pests can also be achieved from planting variety mixtures in the same field which reduces the potential for epidemics.

Crop rotations offer one of the most time-proven and effective means of increasing biological diversity and improving crop productivity known to mankind. It is unlikely that we will substantially increase the probability of a more sustainable agriculture without the use of longer crop rotations. In addition, social and political paradigms will need to change. Social paradigms exert an important influence in the evolution of agriculture in a given nation or region. Perceptions about efficiency, farming as a business or industry, and the role of soil in agriculture have helped to shape the current structure of agriculture in the United States. A goal of more traditional agriculture has been production with the least amount of raw materials and external resources going in thereby maximizing the use of internal inputs. In contrast, the "factory goal" is to move the largest possible flow of raw materials in one end and finished goods out the other end.

One component of sustainability is an increased reliance on renewable resources and on inputs internal to the farm. External inputs are not "bad", but over-reliance on them can be expensive which makes agriculture more vulnerable to a supply disruption or major price escalation. While most farms have a mix of external and internal inputs, diversity enhances the productivity and efficiency of many biological systems. For example, diverse cropping systems and crop-livestock combinations allow farmers to effectively utilize forages and residues, and spread the risk of production over time and space.

Components of a More Diverse Cropping System

THE ROLE OF SOIL QUALITY AND PRODUCTIVITY

Modern technological advances in agriculture have lessened the perceived importance of the soil resource in maintaining a productive agriculture. We have numerous examples of quality criteria for our grain, fruit, and vegetables, but few criteria exist on which to base an evaluation of soil quality. Soil quality can be perceived as combination of factors defined within the concepts of soil fertility and soil productivity. Soil fertility is defined by the Soil Science Society of America as the ability of the soil to supply nutrients to plants and includes factors such as soil pH, available nutrients, etc. Adjustments to overcome fertility problems are made from soil test recommendations for applications of fertilizer nutrients or soil amendments. Soil productivity is the long-term ability of a soil to produce a crop.

Soil quality factors are dependent on good soil fertility, but include factors not easily or routinely determined from a soil test. For example, soil structure is related to the size, shape and stability of aggregates essential for plant health and efficient utilization of soil and fertilizer nutrients and soil water. Larger water-stable aggregates allow soil fauna such as earthworms more habitable space, reduce bulk density, promote soil aeration, increase infiltration of water, and provide space for plant roots to grow.

Plant roots promote soil aggregation through the stimulation of microorganisms which produce "biological glues" that bind soil particles together. Both fertilizers and manures stimulate plant growth which increase root production. However, grasses, and especially natives species, build up soil structure and aggregation quicker than other plants because of the large quantities of fine roots they produce. Some farmers have always emphasized soil structure and tilth in their management by adopting more diversified crop rotations. With the recent emphasis on sustainable agriculture and limiting resources, more farmers are ascribing greater importance to soil structure, earthworms and other soil life. While undocumented experimentally, some midwest farmers suggest that longer term crop rotations reduce the drought risk of their farms, perhaps from better soil aggregation which may increase infiltration and reduce evaporative water loss.

SOIL NUTRIENTS AND CROP ROTATIONS

Inherent soil productivity and fertility can be maximized by a diverse crop rotation. Long-term studies at the Morrow, Sanborn and Pendleton plots in Illinois, Missouri, and Oregon, respectively, clearly show how soil organic matter and soil nitrogen are higher under diversified cropping. Without closed nutrient cycles, the export of crops from a farm will require nutrients to be imported, a need that will be largely met by commercial fertilizers for the foreseeable future. But opportunities do exist for increasing on-farm nitrogen contributions from legumes and for better utilizing native soil nutrients. Energy prices and farm commodity programs will be decisive factors in encouraging such a trend.

Crops such as wheat, corn, and soybeans exhibit higher yield potentials when grown in rotation versus continuous cropping. This phenomenom known as the "rotation effect", is the benefit and sometimes yield decrease when moving away from continuous crop culture. The exact nature of this phenomenon is not completely understood. Corn production in the Midwest illustrates the value of rotation where continuous monocropping of corn offers a farmer some clear benefits—a single line of machinery, specialization of management skills, and maximum returns from Federal commodity programs. But the list of problems is long—high soil erosion potential, depletion of organic soil matter, reliance on high rates of nitrogen fertilizer, insect pests, uneven demands on labor and equipment, and lower maximum yield potential. Over time, the farm becomes increasingly dependent on external production inputs, and thus increasingly vulnerable to disruption of supply or to price escalation.

In contrast, corn production in a 5-year rotation of corn, oats, and 3 years of alfalfa after plowing down of alfalfa requires only 30 to 50 pounds of nitrogen per acre, compared to the 100 pounds or more on continuous corn. The yield potential is typically 10–15 percent higher in rotation, due to the rotation effect. Little or no corn rootworm insecticide is needed, and lower weed pressure reduces herbicide requirements. Ten-year studies by Dr. Gyles Randall at The University of Minnesota Experiment Station at Waseca showed corn yield to be 10 to 15 percent higher when rotated with soybean or wheat than continuous corn regardless of the amount of nitrogen added to continuous corn. These results have implications for farm profitability as well as for ground water contamination from nitrates, due to the diminishing returns of yield per unit of nitrogen as the rate increases.

DISEASES, PESTS, AND WEEDS

Disruption of disease cycles is considered to play a major role in the rotation effect. The concept that a "healthy soil" makes for a "healthy plant" has been postulated for many years (Howard, The Soil and Health), but it has not been researched in depth. Healthy plants utilize nutrients and water from the soil more efficiently. Some farmers contend that healthy plants are more resistant to insects, thus reducing the need for insecticides. An experiment by W. Goldstein at Washington State University indicated that wheat plants in rotation with forage legumes were more competitive with

weeds than when preceded by wheat in a cereal rotation. Studies by R.J. Cook, USDA-ARS at Pullman, Washington have emphasized the importance of plant health and have demonstrated the use of fumigation as a tool to reveal the full yield potential of wheat. A large fumigation response indicates a yield suppression by soil pathogens under field conditions, and is typically highest (up to 70 percent) in continuous wheat and as low as 7 percent in a 3-year rotation. By lengthening the time between wheat crops, one Washington State grower harvests more wheat when cropping only one-third of his land to winter wheat each year (3-year rotation) compared to cropping half his land to wheat (2-year rotation). A crop of peas and sudangrass before potatoes under irrigation in Washington State had an effect on yields similar to that of fumigation under continuous potatoes, indicating the potential of certain crops to "sanitize" the soil.

Crop rotations also help to reduce weed and insect problems. When the same crop is grown year after year, those weeds similar in biology to the crop become a serious competitor, and are often difficult to control. The increasing infestations of winter wheat in the Pacific Northwest with jointed goatgrass provides an example. By including spring crops in the rotation, this weed can be suppressed. Corn rootworm is a serious pest of corn when grown after another corn crop, and insecticides are necessary for control. When corn is preceded by one or 2 years of another crop in the rotation, the life cycle of the insect is interrupted and little or no insecticidal control is necessary.

SOCIAL, ECONOMIC, AND ENVIRONMENTAL CONSIDERATIONS

Diversification through crop rotation impacts farm diversification, resource use, and issues of environmental quality. Mixed cropping can lead to greater economic stability, especially with the inclusion of livestock. Farm diversification leads to more efficient use of resources, greater potential for recycling waste products, a more even demand on labor and equipment, and better nutrient cycling in the soil.

Rotations generally lead to increased reliance on internal farm resources, and through nitrogen fixation by legumes and pest suppression by crop rotation, agrichemical inputs can be reduced which in turn can reduce the potential for environmental contamination of some of these materials. Cover crops and catch crops can reduce both soil erosion and nitrate leaching, and help to protect surface and ground water quality. As world petroleum supplies shrink and prices escalate, cropping systems less reliant on oil-based inputs will be at a competitive advantage.

Along with meeting the demands for environmental quality, diversified cropping systems can address consumer concerns about food quality. Those systems that reduce pesticide use in farm production reduce the chance for chemical residues in the food. The impact of production systems on the nutritional quality of food remains a controversial issue, but some data point to significant differences in vitamins and minerals between different farming methods. Advocates of the family farm in American agriculture suggest that diversified farming keeps more farmers on the land, and this

in turn supports the quality of life in rural communities by maintaining schools and services.

Constraints and Future Directions

Although many benefits of a diversified agriculture are possible, a number of constraints exist to inhibit a move in that direction. Government farm policy has been notoriously influential in preventing the adoption of more diversified crop rotations by farmers across the country. Proposals for the next farm bill that include increased flexibility in crop acreage base, historic yield levels and incentives for crop rotation are a step in the right direction.

Peer pressure in rural communities acts to slow the move towards diversification, as specialization is often seen as a mark of a modern farmer. Also, many farmers would need to develop new management skills and access information that is sometimes unavailable about alternative systems. Thus, it is easier to continue with the current management system.

For some farmers, diversification would require new machinery or facilities, something not feasible where high debt continues to be a problem. Markets for rotational crops can be uncertain and pose a risk. For example, grain farmers have had a guaranteed market with the government program. If they included a legume such as alfalfa in their rotation, with no livestock, the marketplace might not be able to absorb large increases in supply. As farming decisions can be influenced by lending institutions, it might be hard to justify the short-term wisdom of buying new equipment to produce a risky crop.

Along with the interest in farm policy changes that would allow cropping diversification, changes in agricultural institutions and social perceptions are emerging. Farmer-research-extension-community linkages are being expanded and made more multi-directional in an effort to tap the vast amount of on-farm knowledge that exists (C. Francis, University of Nebraska). Federal, State, and private programs exist to help farmers with on-farm testing, and to communicate the successes and failures to other farmers, researchers, policymakers, and the general public (D. Granatstein, Minnesota Land Stewardship Project). Both historical and contemporary research results on cropping alternatives are being interpreted and made accessible for farmers.

Awareness of agriculture's importance and problems by the American public is high, due to to publicity about several controversial agrichemicals. A dialogue is needed between the farming and nonfarming communities to find common ground for future directions in agriculture that meet the needs of both groups. Consumers must be made aware of the true costs of producing food today, and how consumer demands for a year-round supply of cosmetically perfect, low-cost food lead to many of the environmental problems of public concern. Cropping diversification and crop rotation are possible strategies for meeting the needs of both groups. But such changes that lead towards a more sustainable agriculture must occur in the context of a society that is striving for sustainability as well. Some sacrifices from the consuming public may need to be made. The stewardship ethic expected of those who work the land must be shared by those who live from the fruits of the land's productivity.

INTERNATIONAL FORCES FOR AGRICULTURAL SUSTAINABILITY AND THEIR INFLUENCE ON U.S. AGRICULTURE

(By Richard R. Harwood, Winrock International, Morrilton, AK)

This review identifies international forces for sustainable agriculture, shows how they interact with United States agriculture, and identifies needed congressional action.

An Emerging Global Agenda for Development

A quiet but pervasive global revolution is occurring in agricultural development that is defining development pathways for the next several decades. The narrow focus of the 1960's green revolution—on production of food and feed grains in areas of high soil and water resources—bought time under pressure of population increases, but it left much undone and many imbalances. The sustainability revolution consists of a rethinking and consequent broadening of national agricultural development agendas in directions that promise greater sustainability. The response of the United States and of its agricultural sector to this revolution will determine whether it maintains intellectual, technical, and economic leadership and continues to reap the many rewards.

The United States must be compatible with several criteria for assessing agricultural growth that will predominate in many national agendas around the world. The agendas are established, as in the United States, by complex interactions of social, political, and economic forces. The agendas themselves, as well as the processes by which they are established, are undergoing rapid changes. Major items on these agendas include:

FARM FAMILY INCOME

Many developing countries will continue for decades to rely upon agriculture to provide income for the majority of their peoples. In Asia, farm family income now ranks ahead of production on the national development agenda of most countries.

PRODUCTION

Population growth and the need to exploit every resource for national income dictate that massive production increases continue in most developing countries.

PRODUCTIVITY

Efficiency of use of scarce and expensive resources is critical to most countries.

CONSERVATION OF NONRENEWABLE RESOURCES

Soil, water, and genetic resources are in critical balance in many developing countries, and determine their agricultural growth potential.

ENVIRONMENTAL QUALITY

Global, national, and local environments are highly dependent on agricultural technologies. This item is higher on some national agendas than on others.

FOOD QUALITY

The agendas of developed countries are far more specific regarding quality and content than are the developed countries, but change is occurring. International quality standards will increasingly affect U.S. exports.

Many other issues such as worker safety, animal rights, and macrostructure (the geographical location and unit size) are important items on many national agendas.

The way in which agricultural change is planned and implemented is also undergoing rapid change. The top-down approach has decreasing relevance as farm systems become more complex and as national agendas combine a broad array of social and scientific goals. A new profile of grassroots involvement with top-level scientific development is emerging, which has unfortunately put a large segment of the U.S. scientific community on the defensive.

The emerging international forces for sustainability have an impact on the United States through common points of introduction. These include:

—"Export" of education. The United States remains the leading country for training foreign students in agricultural sciences, earning not only import dollars but grounding foreign scientists in democratic values.
—Intellectual and scientific leadership. Americans have been prevalent if not leaders in international agricultural development.
—Export of American technology and agricultural equipment.
—Export of agricultural products.
—Import of agricultural products.
—Shareholders in the global environment.

Unless U.S. agriculture, along with its scientific and educational base, evolves rapidly in directions compatible with the emerging global agenda, we will become increasingly irrelevant in several of these areas and will find our products both noncompetitive and unacceptable in the global marketplace.

Congress can lead the way toward accelerating change in United States agriculture that will maintain our leadership position by creating clear mandates and well-focused but modest programs.

Needed Action

The first area needing attention concerns our land-grant institutions, which form the educational and much of the intellectual base not only for U.S. agriculture but also for our educational and scientific "export." These institutions are changing all too slowly (if at

all) from the traditional top-down technology-diffusion model. They are slow to accept public demand for high environmental quality and for food that is free from artificially high levels of hormones, pesticides, and other harmful substances. They are focused on narrow areas of technology almost to the exclusion of knowledge of integrated farming systems. All three of these weaknesses decrease their effectiveness to deal with the emerging agendas for agricultural development both at home and abroad. Finally, there is little evidence that the U.S. scientific community is gaining sufficient knowledge of the complexities of Third World agricultural development either to educate foreign students effectively or to continue to provide needed scientific input. If there is a future Achilles' heel in United States agriculture, it is deficiencies in land-grant institutions.

The deficiencies in the focus of U.S. land-grant institutions are common to United States and Third World development abilities. In each case, improvements in the United States' focus will markedly affect its ability to lead in Third World problems of the next decade.

RECOMMENDATION 1: LAND-GRANT CHANGES

As a first step, land-grant institutions and their agricultural extension agents should learn to work through the many farmer and nongovernmental organizations that are becoming active in many States. The present "passing acquaintance" relationship should be upgraded to a full partnership, with farmers being encouraged to take the lead in conducting on-farm trials for adapting technology and designing systems. There is a small start in this work with the Low Input Sustainable Agriculture (LISA) program. This work needs to be more fully conceptualized and the patterns and technical areas spelled out wherein bottom-up development has a role. The farming systems on-farm work in Asia has left the U.S. scientific community well behind in this regard.

This new balance between farmer/local community input and top-down input is crucial to effective work in most Third World countries. Its principles can be learned equally well in the United States. Its need has little to do with low-input technologies, but the many farmer organizations involved with low-input agriculture make this a logical place to start. Until such time as the U.S. land-grant community fully participates in such activities at home, its scientists will be ill equipped either to work in applied development overseas or to teach its methods to the many foreign students now receiving their basic science here.

Our scientists should learn the integration technologies of crop rotations and of crop/animal integration for nutrient cycling, for weed and pest management, and for resource-use efficiency. Third World systems are based on those interactions. Many feel that U.S. systems should make more use of these integration efficiencies. The methods for their study, the computer models for their conceptualization, and the systematic approach to their understanding are as common to U.S. integrated systems as to Third World small-farm systems. U.S. scientists could well be leaders in this area.

The integration of systems to optimize production with minimal inputs of manufactured products is crucial to Third World development, where limited infrastructure, lack of foreign exchange, and a labor/cash input balance all favor increased integration and low inputs. Production costs and environmental impact dictate that this approach be taken seriously in the United States.

Finally, there is a need to experience and understand Third World systems and to bring that experience back to U.S. classrooms and laboratories. That can best be done by U.S. scientists who have solid background in their technical specialties and experience in bottom-up development, systems integration, and low-input approaches. Such scientists could be placed in Third World development programs for short periods of time to teach, learn, and conduct research. The locations must be in national programs and within national line agencies as opposed to academic or international institutions.

To encourage such activity, a grants program could be envisioned as an adjunct to the U.S. program wherein a small interdisciplinary team would participate in LISA. The team's efforts should concentrate on farmer-collaborative research on integrated systems, preferably of low-input technologies. Carefully chosen Third World study/research assignments would be an integral part of such a U.S.-based program. The objective would be to have at selected land-grant institutions, groups of applied scientists in plant and animal sciences who would be expert in the integrative approaches and technologies that are common to both U.S. and Third World agricultures and that are central to their sustainability.

RECOMMENDATION 2: FOOD QUALITY IMPROVEMENTS

A second area of interaction of U.S. agriculture with international forces for sustainability involves hormone and chemical use in U.S. production of animals and crops and the resulting traces of those compounds in our exported products. In many developed countries, consumer awareness of food quality is ahead of that in the United States. Our products will come under increasing scrutiny in those countries, with consumers demanding that their own national standards be met.

An example is the present concern in Europe over content of synthetic hormones in animal products. The consumer concern over food quality and its content of certain synthetic production compounds, whether pesticides or growth hormones, has grown much faster than in the United States and has become much more politicized. The banning of synthetic animal hormones in Europe is the result of widespread consumer and environmental concern, influenced at least in part by concern over animal rights. Support for regulation has thus been widespread and deeply rooted. The refusal to accept imports of beef containing such compounds is supported partly by consumer demand and partly by support from growers who rightly fear that production costs in countries using these compounds may be lower. There may be other elements of "protectionism" as charged by the United States, but the conflict is far more deep rooted than that. The European Economic Community's administrators cannot make simple changes in the import policy. Re-

taliatory boycotts are unlikely to have effect, as the ban is a result of a broad, development agenda with widespread and extremely strong political support. The ban can be reversed only with basic agenda changes.

A careful study of the U.S. agricultural agenda would show that we follow the European agenda in many respects, with a lag time depending on the issue. The implications are clear, however, that U.S. exports will come under increasing scrutiny as national agendas continue to evolve. This will add impetus to the forces already prevalent in the United States to reduce chemical inputs in our crops and livestock. The agendas of most Third World countries are relatively silent on this issue and will probably continue to be less restrictive than our own; but these countries import only modest amounts of our agricultural products.

RECOMMENDATION 3: MARKET OPPORTUNITIES

A third area of interaction involves the increasing production of a wide range of high-value tropical products including fruits, spices, silk, and similar products in Third World agriculture for potential export. These products fit well in the low-soil and water-resource areas of the Third World that were bypassed by the green revolution. They add significantly to small-farmer income and figure prominently in national development plans. Most of these crops and perennials add both economic and environmental stability to extensive areas of fragile lands. For example, in the Philippine province of Pangasinan, over 1.5 million mango seedlings are being distributed to farmers during 1989 in a massive effort to increase small-farm income. Most of the production from the area now goes to Singapore and Hong Kong. As new plantings come into production in future years, large volumes will be available to other markets. This is being repeated across Asia with a wide array of similar products designed to stabilize the environment and increase incomes through diversification. U.S. business interests should be well aware of this production trend and respond to it. Information on such trends should be made available to U.S. farmers.

RECOMMENDATION 4: SMALL-SCALE MECHANIZATION

A fourth area is the need for small-scale mechanization. The United States, with a few notable exceptions, has neglected this field. We continue to have major export of small gasoline engines, but we have failed to take advantage of the rapidly growing market for small diesel engines and for other small-scale equipment such as threshers. The production of food and feed grains will remain small scale in the Third World for the foreseeable future, with growing markets for harvesting aids and threshers. A huge but overlooked market is that for hand tools. Those of us working in Third World agricultural development are appalled at the poor quality of hand tools around the globe. It is ironic that European and North American hand tools are far superior to anything available through local manufacturers, particularly in Africa, yet we completely fail to take advantage of the market opportunity.

RECOMMENDATION 5: MEASURING ENVIRONMENTAL QUALITY

A fifth area of interaction involves the measurement of environmental quality. There is increasing demand for equipment and expertise in creating national data bases for air and water quality and for monitoring food quality. The United States is a leader in this field. We have not shared that expertise in our development programs nor have we taken advantage of business opportunities in that area.

RECOMMENDATION 6: CIRCLE OF POISON

A sixth interaction area is in our export of agricultural chemicals. We do not impose the same restrictions on export materials that we apply to domestic sale. Much has been made of the "circle of poison." There is increasing pressure to tighten inspection of products coming into the United States to eliminate reintroduction of banned materials. There will be increasing international pressure not to export these materials, coming from U.S. consumer interests as well as from countries whose awareness of human and environmental issues is increasing.

The export of U.S.-made agrichemicals to Third World countries is a time bomb in the area of worker safety. Virtually all chemical use in those countries is by hand application. Many of the extremely toxic materials such as methyl parathion are virtually impossible to apply by hand under tropical conditions with worker exposure approaching U.S. standards. Sooner or later, political if not moral pressure will force industry response to this very real problem.

RECOMMENDATION 7: ANALYSIS OF AGRICULTURAL SYSTEMS

A final area of attention is that of analysis and establishment of guidelines for the macrostructure of national agricultural systems. Our lack of such analysis in the United States has led to ground water depletion, overgrazing, decertification, and overconcentration of animals in certain watershed areas, leading to contamination and eutrophication.

Third World countries are making the same mistakes by overconcentrating poultry, swine, and milk production around metropolitan areas and overdrafting ground water. The expertise for analyzing appropriate location and scale to protect the environment and to accomplish socioeconomic goals has not been developed in the United States. It is needed as much here as in the developing world.

In summary, the global revolution in national agendas for agricultural sustainability has many implications for U.S. agriculture. Many of the emerging forces present warnings, challenges, and opportunities for United States scientists and industry. Some of the emerging problems are common to the United States and the Third World. If we are to remain in a position of leadership—scientific, economic, and moral—we must continue to evolve rapidly toward greater sustainability. There is scope for congressional action in that evolution.

BIOTECHNOLOGY

AGRICULTURAL BIOTECHNOLOGY—AN OVERVIEW OF ISSUES FACING POLICYMAKERS

(By Robert B. Nicholas, McDermott, Will & Emery, Washington, D.C.)

Like all powerful new technologies, biotechnology presents great promise while, at the same time, challenges society by raising questions about its applications and impacts. In the first section of this paper I have attempted to identify the relevant public policy questions concerning the applications of biotechnology to agriculture as background for the 1990 farm bill. In the second part of this paper, I provide a summary of the other papers in this section.

What is Biotechnology?

To some, biotechnology is evolutionary, finding antecedents in traditional plant breeding, microbial selection, animal husbandry, and fermentation processing. To others, biotechnology is revolutionary, created by the enhanced control biotechnology gives over traditional activities. Biotechnology can be described in many ways, but principally biotechnology has given society a better understanding of biological processes at the molecular level, and it has substantially increased our ability to use and manipulate those processes more precisely and in real time. Biotechnology is not an industry, but a broad base of technologies with applications in human health care, agriculture, consumer, and industrial products.

Impacts

Biotechnology has increased the basic understanding of life's processes at the molecular level; sporned the formation of hundreds of new companies and investment of billions of dollars; become a dominant force in the university, integrating biology with other sciences and attracting millions of dollars in governmental and private research; and generated public debate surrounding the direction the technology should take and its potential impact.

Biotechnology is viewed by many as possibly having the greatest impact on the agriculture sector of society. Those potentially affected include: farmers and producers, agriculture input providers and processors (chemical, seed, processors and sellers), research establishments, and the general public (consumers, environmentalists, animal welfare groups, and the like).

Enthusiasts view biotechnology as having the potential to reduce farming-related environmental costs, produce healthier products and enhance farm efficiency and productivity. For example, biotechnology is producing target-specific biological pest control agents to resist various viruses, and thereby lessen dependence on chemicals (tomatoes with TMV resistance); and biotechnology is producing genetically engineered copies of species specific animal

proteins, such as Porcine Somatotropin (pST), which, field trials have demonstrated, enhanced feed efficiency in pigs and produce leaner pork.

Some who are equally optimistic about the potential of the technology are concerned that the applications chosen for commercialization may not meet their needs and goals. Others speculate that the applications of biotechnology may impact their economic viability or change their way of life. Some small dairy farmers, for example, feel they may not be able to compete with those farmers who utilize Bovine Somatotropin (bST), a protein drug shown to enhance feed efficiency and milk production in dairy cows, and which is expected to be approved by FDA within the next year. Still, others raise concerns about potential impact and unanticipated consequences on the environment from planned introductions of engineered microbes, and about food safety from products produced from genetically-engineered plants or microbes. Some also have ethical concerns about manipulation of life forms and oppose the applications of the technology because they generally oppose new technologies.

The agricultural sector in our society is dynamic. The way products are grown, processed, and marketed has changed dramatically during the past decades and will continue to change. Today, more food is produced by fewer people, new technologies and new products are being made available to food producers and processors at a rapid pace, and there is fierce competition for international markets. In addition, today more attention is being paid to environmental, health, and nutritional concerns associated with producing and consuming food than decades ago. This is the climate in which biotechnology will reach the farmer, processor, and consumer. As with any technology, biotechnology will compete with other technologies, and it will be successful only to the extent it offers processes and products that are, and perceived to be more efficient, more profitable, and more desirable.

The 1990 Farm Bill: The Challenge and Opportunity

Because of the power to alter living organisms, and because of the broad scale of application, biotechnology has become the focal point for public debates and Congressional attention across a broad spectrum of issues including, agricultural policy (direction and funding of publicly-supported research); international competitiveness; environmental degradation; low input and alternative agriculture; animal welfare; family farms; nutrition, safety and quality of food. Some of these issues are familiar ones (e.g., the allocation of research dollars), while others are new (e.g., the patent protection available for life forms). In some instances, biotechnology is really the issue, in others biotechnology is merely the vehicle to discuss ongoing issues between old protagonists.

Our challenge as a society, and the challenge for Congress in the 1990 farm bill, is to (1) use the farm bill to establish the public agenda for biotechnology so that the best potential of the technology is realized; and (2) use the farm bill as a vehicle to implement the public policy goals as defined. To accomplish these objectives, we need to identify the salient issues, separate misconceptions from

reality, obtain relevant data and, identify the real parties affected. In short, the challenge is to solve the real issues between the real parties in interest, and not to be diverted by extraneous issues for which biotechnology is not the cause and cannot be the cure.

The Major Public Policy Issues:

Research and Development

While there is wide-spread support for the use of biotechnology in agriculture, there is not yet a public consensus as to the general direction and specific application of biotechnology. Because there are few products actually at the farm gate or in the market place, farmers and consumers have yet to make choices and much of the debate has centered around ideology. As such, much of the discussion to date has been based on hypothetical situations and speculation on environmental, economic and sociological benefits and risks. The challenge is to develop a consensus on the goals to guide public policies and public funding of biotechnology in agriculture.

To date the debate has focused on two central questions: How much is needed and, for what purposes should the funds be used? Proponents of biotechnology would like to see major new commitments from USDA to fund plant biology research, such as the Board on Agriculture's call to increase funding for competitive grants to $500 million.

With respect to private investment, most would agree that the private sector should be free to choose their targets of opportunity based upon short-term profit motives. However, questions have been raised about public policies and funding decisions that arguably do not take into consideration long-term goals and a more public agenda. Long-term goals, such as the development of crops that rely on fewer inputs and the development of non-chemical pest control agents.

Ironically, many of the goals for biotechnology on the public agenda are generally shared by the private sector, tempered by the need to have short-term time frames, economic and technical feasibility, and sufficient profitability. For example, the first research and commercial targets are vaccines, plants, and animal drugs which are safer, lessen dependence on older more toxic chemicals, and produce superior consumer products: subunit vaccines; bST and pST, natural proteins without residue concerns used to enhance feed utilization and production; pest-resistant plants—that substitute Bt (with a 20-year safety record) for more toxic compounds; herbicide-resistant plants—that reduce the need to use older more toxic pesticides.

Nevertheless, questions have been raised about how well these substitutes meet broader goals, whether alternative products could do a better job, and whether these products have secondary effects, such as potential economic dislocation, and what other desirable products are not being developed?

Assessing the Impacts of Biotechnology

If we are to develop goals for biotechnology, an essential part of the process is the capability and willingness to undertake technology assessments. The challenge for the government is to develop an

institutional framework for technology assessment, use the information to develop government policies that leverage the benefits and cushion the adverse impact of private sector decisions.

Biotechnology's impacts on agriculture will, in some cases, accelerate existing trends. In other cases, it may create new trends. Some of the questions that have been raised include: whether the technology will be too costly or not "user friendly" for smaller-scale operations; whether the technology will enhance productivity to the extent that it depresses market prices; whether the market will provide incentives to encourage adoption of a safer new technology; and whether regulations will unnecessarily impede the commercialization of safer alternativesto existing technologies.

Developing a Rational Regulatory Regime

The products of biotechnology can be either living organisms (i.e., a microbe, plant, or animal with modified genetic properties), or the product of a new organism (i.e., a food enzyme, drug, or chemical produced by a recombinant organism). Establishment of a regulatory regime for biotechnology has focused primarily on the former, where modified organisms are intended to be introduced into the environment.

The basic framework for regulation of field research and commercialization of biotechnology in agriculture was articulated in June, 1986 and 1987, and is based on existing laws, supplemented by guidelines and regulations. As new applications of the technology develop, the framework must be refined to meet new and unforeseen needs. In the view of many, the current system, though far from optimum, is acceptable and working. The National Academy of Sciences, the Ecological Society of America, the Office of Technology Assessment and the Boyce Thompson Institute, among others, support the conduct of appropriately planned and reviewed small scale field tests to gather additional information. To date, USDA and EPA have approved several dozen field experiments of transgenic organisms. All of the field introductions received wide public attention, all have been extensively reviewed by the government, and all have been successfully conducted without, as far as it is known, any adverse effects on health or the environment.

Nonetheless, others believe that the current system can be improved and some believe that new legislation is necessary. Legitimate questions concerning the regulatory scheme, such as the scope of the regulations and their complexity; intergovernmental coordination; the treatment of confidential information; uncertainty with respect to review of commercial applications and new applications (e.g., transgenic animals); are raised.

As with any debate about governmental regulations, the challenge is not so much to prevent anticipated adverse consequences, but how to lessen the potential for the unintended infrequent adverse consequences without unnecessarily regulating new technology. With respect to biotechnology, the task is to continue to develop a data base, allow specific products into the field and market after appropriate review and testing, and keep flexibility in the system so that exemptions from regulation can be established, or additional controls established, as experience dictates.

Information, Access, and Perception

For biotechnology to thrive in agriculture, the public, policymakers, and farm community must have accurate and meaningful information regarding the technology. The challenge in this arena is to expand and upgrade the basis of the dialogue, present facts to farmers, consumers and the public, and make decisions based on facts, and not merely "perceptions" of fact.

The farm community must have information in order to assess the benefits and risks associated with the technology. For the farmer, the decision is frequently an economic one—will the cost of acquiring the technology be adequately repaid—the decision may be based on environmental, social, ethical, and other factors as well. Of critical importance is the attitude of the consumer toward the end product—that is, will the consumer buy milk from cows treated with bST?; how will the consumer react to a tomato that is not sprayed with an insecticide because it is genetically engineered to express Bt?

So too, the public must have information necessary to participate in the policy debates and the regulatory process. The public must also have information to make choices about new products. However, care must be taken in this latter case, lest new products be singled out and information on their attributes presented in a fashion that heightens concern, and safer new products are prevented from coming to the market.

There are, of course, legitimate questions that should be raised, evaluated and discussed about specific applications of biotechnology. It is easy to see, however, how emotion can dominate a debate about biotechnology in a country with wide-spread scientific illiteracy, questions about the credibility of the government, a distrust of industry, scientific uncertainty, and complex scientific issues.

Groups like the Keystone Center have played a major role in providing a forum for discussions of various aspects of biotechnology, and together with other groups, have expanded both the public education and information dialogue. The government, academic institutions, and scientific societies must play a greater role so that those opposed to the technology are not able to tap into public fears about technology, and unfairly exploit them.

Conclusion

Biotechnology is complex in both its science and societal impacts. There are great potential benefits to society generally, and to the farm/food community, if as a society, we are able to sort out conflicts and develop a consensus.

Summary of Papers

The papers that follow discuss several topics: the opportunities presented by the application of biotechnology in agriculture; methodologies, principles, and issues concerning risk assessment when introducing genetically-modified organisms into the environment; regulation of biotechnology; and a viewpoint from the farm and environmental community on the benefits and directions of biotechnology.

The Opportunities

In his paper entitled "An Overview of the Biopesticide Industry," Jerry Caulder makes the case for developing and using biological (bacteria, fungi, and viruses) pest controls.

The author believes that biocontrol is attractive to society because it lessens dependence on chemical pesticides and because biopesticides are generally toxic to target pests only; have low capital costs of production and they are biodegradable and safe for the environment. However, biopesticides concern farmers who want pesticides that are long lasting, broad spectrum and quick acting. In the author's view, biotechnology can solve the farmers' concern while retaining the societal benefits.

Dr. Caulder recommends that the 1990 farm bill contain incentives for farmers who adopt biopesticides as part of their pest control program and increased funding for agricultural research, including competitive grants and increased Federal support for risk assessment. Dr. Caulder also recommends that new regulation for biopesticides not be promulgated.

Richard Godown, in his paper entitled "New Products in Biotechnology," presents an overview of the applications of biotechnology in agriculture. He concludes by supporting the Board on Agriculture's call for an increase to $500 million in Federal support of competitive research grants in agricultural biotechnology and for improved intellectual protection for agricultural inventions.

In Mr. Godown's view, biotechnology—a set of safe techniques for developing new products and improving microbes, plants, and animals—has the potential to make farming more reliable and cost effective. He also believes that biotechnology can produce foods of higher quality, protect the environment through use of biodegradable products, and help developing countries feed their people. Among the applications identified by Mr. Godown are crops with improved growing characteristics; crops of higher quality; new crops, for food and non-food uses to open new markets for farmers; plant and animal diagnostics, vaccines, drugs, and other products to diagnose and detect residues and contamination; microbes for nitrogen fixation and other purposes; and transgenic animals.

In the third, and final paper on the opportunities for agricultural biotechnology, Hugh Bollinger and Dale Hanse, in their paper entitled "Implications of Plant Genome Mapping," support enhanced efforts to map plant genomes using a new technology called Restriction Fragment Length Polymorphism (RFLP's).

Citing the historical role of crop genetics in enhancing crop productivity and quality, the authors explain how gene mapping can precisely identify the genetic control for specific traits, and how such information can be utilized in plant agriculture. The authors call for enhancement of Federal leadership and support for gene mapping; establishment of specific goals to meet national needs, such as development of new crops that require less chemical inputs and crops that fit into programs of sustainable agricultural operations; enhancement of opportunities for collaboration between universities, industry, and governmental laboratories; and establishment of national gene mapping standards.

Risk Assessment

In "The Planned Introduction of Genetically Engineered Organisms: Ecological Considerations and Recommendations," the Ecological Society of America (ESA) endorses the development of environmentally sound products through the use of biotechnology within the context of a scientifically based regulatory policy that encourages innovation without compromising sound environmental management. The ESA lists three types of questions that need to be explored: (1) questions concerning the new trait that has been engineered into the organism; (2) questions concerning characteristics of the "parent" (wild type) organism which has received the trait; and (3) questions concerning the environment into which the organism will be introduced. Primary conclusions from the report are: (1) genetically-engineered organisms should be evaluated and regulated according to their biological properties (phenotypes) rather than the genetic techniques used to produce them, and (2) the use of small-scale field tests, when justified by previous laboratory and/or greenhouse studies under conditions that minimize dispersal and under appropriate regulatory oversight, is encouraged. The ESA supports several of the principles in the current regulatory framework, criticizes others and supports cooperation in risk assessment and management.

In the second paper entitled "Integrating Biotechnology Into Agricultural Systems," Fred Gould encourages USDA–ARS and land grant universities "to do proactive, applied research that will promote the development and use of agricultural biotechnology in ways that will offer maximum long-term environmental and societal benefits." The author recommends that the 1990 farm bill structure subsidy programs "in ways that would promote interaction between farmers and researchers in testing innovative biotechnology products."

Using as an illustration insect adaptation and resistance to chemical pesticides, the author suggests that current genetic engineering strategies to develop pest-resistant plants (e.g., Bt) perpetuate this problem because they depend on a continuous toxic effect in all tissues of the plant. Gould advocates use of genetic engineering strategies to lessen the probability (or time) that pest resistance develops, by, for example, developing cultivars that would only express the toxin in specific tissues or at specific times. Gould recommends that the research section of the farm bill provide USDA with funding to support such strategies and that incentives, such as those used in the tobacco excess allotment program, be used to encourage farmer participation in large-scale field trials of such cultivars.

Regulation of Biotechnology

In the paper entitled "USDA's Oversight of Biotechnology," Rebecca Goldburg examines the basis for oversight by APHIS and the ABRAC, and makes suggestions for improvement. Dr. Goldburg also suggests steps that can be taken to limit environmentally undesirable, but unregulated indirect effects of herbicide tolerant plants (HTP's).

The author finds APHIS' regulation under the Plant Pest Act "legally and scientifically flawed". To remedy the deficiencies, the author calls for Congress to provide APHIS with an explicit mandate to regulate GEO's used in agriculture, "including those engineered with techniques other than RDNA or that do not contain genes from a plant pest," and for Congress to stipulate that "APHIS shall not approve the release of any GEO where there is a reasonable expectation that the release will significantly harm natural communities of organisms or otherwise cause significant environmental harm." The author also calls for greater public participation in APHIS evaluations by restricting claims for confidentiality. Dr. Goldburg also makes recommendations to address potential conflicts of interest on the ABRAC.

Edward Korwek's paper entitled, "Agricultural Biotechnology Oversight," reviews the recurring problems surrounding the application of current laws to biotechnology, and concludes that "a quick legislative fix simply does not exist for many of these problems." Because "modern biotechnological methods often raise many old issues or problems in a new context, suggesting 'biotechnology-specific' remedies. is often difficult without also addressing the more fundamental problems associated with oversight under any statute."

Finding no unified theory of oversight of research or commercial applications of biotechnology, the author supports continuation of the administrative approach under the current legal framework. Nevertheless, Dr. Korwek finds some areas more amenable to legislative solutions and he also supports high levels of funding for agricultural biotechnology and a clear separation of research and regulatory activities within USDA.

At the Farm Gate

In her paper entitled "Opportunities for Farmers," Ann Sorensen examines three areas: what the farmers need; what role the Extension Service can play; and how the farm bill can encourage adoption of new technologies and alleviate potential problems.

Because of industry's need to focus on short-term profitability, the author believes that several areas of research for farmers may be ignored. Included in this category are the development of alternatives to replace "endangered pesticides"; development of cultivars that are more efficient users of inputs; and the development of technologies to preserve genetic diversity. Ms. Sorensen's recommendations are intended to identify research priorities to meet the needs of farmers, to facilitate development of research objectives, and to improve environmental quality.

The author also discusses the role of the Extension Service in educating farmers about new technologies and recommends the enhancement of Extension's role.

In the last section of her paper, Ms. Sorensen addresses how the farm bill could affect the development of biotechnology to better meet farmer's needs. Her recommendations include enhancing coordination at USDA between agencies; developing an integrated program to use technology to reduce environmental problems and to enhance farm profitability; enhancing technology transfer pro-

grams between researchers and farmers; augmenting substantially the Competitive Grants Research Program, as recommended by the NAS Board on Agriculture; and generally encouraging R&D in a thoughtful manner.

In the last paper in the biotechnology section of this report, entitled "Sustainable Agriculture and the Other Kind of Biotechnology," Jack Doyle finds that the current direction of biotechnology will "extend and reinforce a whole range of agricultural practices and products that will continue to pose environmental, public health, and economic problems" and he makes the case "to turn the 'new biology' in a more sustainable direction".

Mr. Doyle finds that the "dogma" of modern agricultural science and policy has been high-yield, which depends on a high level of costly inputs. The author asks whether such a system can be sustained in terms of cost to the farmer and to the environment, and whether integration of biotechnology into such a system will be "durable and profitable over time". Using as examples herbicide-resistant crops and biopesticides, Mr. Doyle finds they suggest a continuation of environmental and public health problems.

In contrast to this vision for biotechnology, the author calls for "another possibility . . . one that does not presuppose the use of genetic engineering . . . [but] the use of common sense and thoughtful biological application". The author calls for utilization of a neglected "huge treasure trove of 'old biology' and common-sense farming practices" found in the land-grant universities, agricultural experiment stations, and research centers.

The author makes two principal recommendations for inclusion in the 1990 farm bill. The first recommendation is for the establishment of a major new initiative to emphasize sustainable and low-input agriculture. The second recommendation is for Congress to state clearly that the purpose and goals of agricultural research at the nation's land grant universities, is "to serve a broad social purpose that goes well beyond farmers and improving farm productivity, but also extends to the welfare of the rural community."

BIOTECHNOLOGY: OPPORTUNITIES

AN OVERVIEW OF THE BIOPESTICIDES INDUSTRY

(By Jerry Caulder, Chairman, President and Chief Executive Officer, Mycogen Corporation, San Diego, California)

Thirty years ago, I had my first encounter with a pesticide. My father and I sprayed some cotton on our Missouri farm with the herbicide Karmex. Three weeks later, it was obvious that the way we were controlling weeds had changed forever.

Up until 1958, we had controlled crabgrass in cotton with a hoe, a lot of people, a lot of sweat, and about 300 geese. The chemical era brought us and other American farmers important technological innovations that controlled pests and improved farm efficiency and profitability.

During my tenure at a traditional chemical company, it was clear that the industry thought the use of conventional pesticides helped farmers not only provide a reliable supply of food, but also improve the quality of food.

Over the years, however, we've learned that synthetic pesticides leave residues in foods and have been found in ground water. While these residues and ground water contaminants may not be harmful to consumers, consumers have clearly made their choice—they want assurances that their food is safe to eat and their water is safe to drink—and that both are pesticide-free.

What we're seeing now, as we approach the 21st century, is the waning of the chemical era and the beginning of the biological era. We now have the ability to deal with nature's problems using the tools that nature has given us.

We are developing the ability to help farmers control pests and produce a reliable and quality supply of food, while meeting the consumer's demand for pesticide-free food and a clean environment.

The concept of biological control and biopesticides is appealing from an efficacy, commercial and environmental standpoint. Biopesticides are toxic to their targeted pest and do not harm beneficial insects or damage crops; capital costs for production are usually low (fermentation is the normal method of production); and they are biodegradable and safe for the environment. Biotechnology gives us a biological solution to the pest problem.

Overview of the Industry

Let me briefly review the biotechnology industry and its agriculture sector, as well as the status of biopesticides in particular. According to the latest edition of the U.S. Commerce Department's *U.S. Industrial Outlook,* the market value of products derived from biotechnology will reach $1.2 billion this year. By the early 21st

century, the market value of the industry could reach $40 billion a year.

U.S. sales of biopesticides and other biotechnology-derived agricultural products is predicted to exceed approximately $2 billion by the mid-1990s.

Biopesticides currently represent $35 million in the U.S. pesticide market. By the turn of the century biopesticides could capture 15 percent of the worldwide pesticides market.

Biotechnology companies are using natural agents, such as bacteria, fungi and viruses, to develop biopesticides. Many companies, including mine, have discovered—with the help of advanced molecular biology—new varieties of the well-known bacteria called Bt (Bacillus thuringiensis) to control pests.

The Bt bacteria produces a gene that codes for a toxic protein. The protein is harmless to plants and other insects, but is destructive to target pests. A small amount of the protein fouls up the pest's digestive track so thoroughly that the pest stops eating and eventually dies.

Bt biopesticides have been discovered that control Colorado potato beetles, elm leaf beetles, European and Southwestern corn borers, velvet bean caterpillars, soybean loopers, corn earworms, and armyworms.

Bioherbicides and biofungicides have been developed as well. My company uses a fungus *(Alternaria cassiae)* as a bioherbicide to kill sicklepod and coffee senna weeds, problem weeds for soybean and peanut growers.

Another company uses a live fungus to control northern jointvetch in rice and soybean. A biofungicide based on live bacteria also has been developed for use on cotton.

Biopesticide Issues

Three areas make microbial pesticides desirable from an environmental standpoint, but have been perceived as a liability from a commercial and farmer viewpoint. They are persistence, spectrum of control, and speed of action. Biotechnology is being used to make biopesticides more commercially viable, while retaining their environmental advantages.

Persistence

Biopesticides degrade quickly, which is a major environmental advantage. The toxins produced by bacterial pesticides are generally proteins. Proteins are fairly fragile molecules. Once exposed to the environment when they are applied to control pests, they degrade rapidly. The sun and other natural elements break down the protein.

This environmental advantage of biopesticides is a disadvantage (in some cases) for farmers. Because biopesticides degrade quickly, they do not linger as long in the field. Multiple applications are needed to control insects that mature over long periods of time, driving up the expense.

Until now, we have had to live with the product that nature gives us in whatever package it comes in. With the advances inmolecular biology, we in industry have the tools to develop new deliv-

ery systems that create new "biological packages" that protect biopesticides from the environment.

At Mycogen, we let nature microencapsulate our Bt toxin. The gene that produces the toxin is genetically engineered into an organism that offers protection to the toxin when placed back into the environment. We can dramatically improve effectiveness with biotechnology.

Spectrum of control

Biopesticides are pest-specific—they are toxic only to the target species. This has been a commercial liability because farmers perceive that they have a whole host of insects attacking their crops at one time and must spray their fields with large doses of different insecticides.

In actuality, for any given crop, only one or two insects cause 95 percent of a farmer's economic losses. Pest-specific biopesticides provide excellent control for farmers, without "scorching" the earth. Biotechnology, if you will, allows farmers to use a scalpel rather than a meat cleaver to control pest problems.

If a product is needed to control a greater spectrum of pests, biotechnology gives industry the tools to add multiple toxins into the delivery organism.

Speed of action

Farmers believe biologicals kill too slowly, permitting a lot of damage to the crop while waiting for the pest to die. Yet, this is also a perception rather than a technical obstacle. With the techniques of biotechnology, we can toxic load an engineered organism so that the target insect stops feeding after a couple of bites.

A final point about biopesticides is insect resistance. Insects, in short periods of time, have built up resistance to synthetic pesticides. With biopesticides, the chance of insect resistance is remote.

Naturally occurring protein toxins are not new molecules in the environment; evolution has taken care of how the environment can deal with them. They are biodegradable; whereas with chemicals, many are new to the environment and there are no naturally occurring counterparts. This can lead to buildups in the food chain and ground water, both undesirable occurrences.

Preparing for the Farm Bill

As deliberations begin on the 1990 farm bill debate, I suggest that there are several fundamental assumptions that must be considered:

- Biopesticides do work. I hope my earlier overview succeeds at explaining the value of biopesticides.
- We must change a mindset among mainstream agriculture. I am sure the mere mention of the word biocontrol conjures up images of organic farmers telling the world the virtues of pesticide-free food. That's not what the pesticides coming out of biotechnology are about. It is important that new technologies be considered for their value and effectiveness in farm operations.
- Current agricultural surpluses must not be a deterrent to adopting new technologies that can improve farmer efficiency and

productivity. In this land of seemingly inexhaustible surpluses, we have become complacent about our food supply. The population of the Earth is now at the 5 billion mark and will double in 35 years. In the next three decades, we must produce as much food as we have produced since the beginning of our history.

Last year, before the major impact of the drought was felt, our surplus of wheat and feed grains would not even last for 7 months and if it were used to feed the people around the world, it would be exhausted in less than 2 months.

It is interesting to note how our nation views surpluses. A 2-month supply of agricultural commodities is considered a surplus, while a 200-year supply of oil is considered a strategic reserve. In part this view may be due to the notion that agricultural production is renewable while other resources like oil are not.

However, agricultural production is highly volatile and is vulnerable to the impacts of weather and pests. For example, last year's severe drought cut our agricultural surplus in half, leaving the United States with only a 3-month supply—a 50 percent reduction in one season.

It is also important to remember that our very existence is dependent on less than 20 species of plants and that 70 percent of our food comes from only five crops. Agriculture's challenge is to apply quantum leaps in science, to assure that nothing goes wrong with this narrow range of plants that we depend on and to protect them from pests.

• The current challenge facing agriculture is how to produce a safe and reliable supply of quality food at a reasonable cost to the consumer—and at the same time, protect our natural resources.

This final point summarizes what I see as the major objective of the 1990 farm bill. I submit that new technologies are essential if farmers are to produce a safe and reliable supply of quality food at a reasonable cost to the consumer, and at the same time, protect our natural resources. The primary new technology is biotechnology.

Organic farming and low-input sustainable agriculture programs offer exciting possibilities to reduce our use of man-made, environmentally damaging pesticides. However, these programs may not provide sufficient pest control to farmers, nor produce a quality product acceptable to consumers. The consumer also will have to pay the price. Organic farming adds 10 to 50 percent to the cost of food, and it is not as effective in high temperature, high-humidity regions such as Texas and the Southeast.

Biopesticides, on the other hand, have the potential to reduce the use of synthetic chemicals, control pests, and provide a reliable supply of food at a reasonable cost to the consumer.

Further down the road, farmers will have improved plants that resist pests, weeds and viruses. The problems we've seen recently with droughts may be resolved, thanks to drought-resistant plants or plants engineered to tolerate salt, thereby allowing farmers to irrigate with sea water. These advances, however, will not be commercially available until the late 1990's and beyond.

Biopesticides, on the other hand, are currently available and on the market. The Environmental Protection Agency has already approved several bioinsecticides and bioherbicides. EPA has many

products currently under review, which will be available to farmers in 1990.

Biopesticides will not eliminate the need for chemical pesticides. But biopesticides will reduce greatly our dependence on chemical pesticides. They work in conjunction with chemical pesticides to control crop pests, and will play an important role with conservation and low-input, sustainable agriculture programs.

Let me summarize by quoting the recently published National Research Council report "Alternative Agriculture." It reports "genetic research could greatly reduce pesticide use, increase the profitability of legumes and cover crops in crop rotations, and lessen chemical levels in the food supply and environment . . . the committee believes that biotechnology has much to offer farmers looking to adopt alternative production practices."

Policy Recommendations

I submit that our agricultural policy should take into consideration and promote new technologies. Agricultural policy should facilitate, and not impede, the research and development, as well as the adoption, of the new generation of biologicals that are available to replace chemical pesticides.

I offer the following policy recommendations for consideration:

• *Incentive Programs:*

The 1990 farm bill should provide incentives for farmers who adopt biopesticides as part of their pest control programs. Biopesticides, and other products of biotechnology such as improved plants, should be acceptable tools for farmers to employ in LISA and other conservation programs.

Historically, our nation has paid farmers to take land out of production, and not to produce. We've never given farmers incentives to produce in an economically efficient manner that is compatible with the environment.

One incentive-reward program might be to require farmers who participate in the Acreage Reduction Programs or paid diversions to develop and implement a pest control program aimed at reduced chemical use in order to qualify for full deficiency and other financial payments.

Or the incentive might be tied to farm program eligibility, much like the Conservation Reserve Programs. To be eligible for farm program benefits, for example, farmers would have to develop and implement a USDA-approved pest control plan by a certain date.

• *Pesticide-Free Food:* National food certification programs have been proposed that would set standards and other requirements to verify that food has been produced without the use of conventional chemical pesticides. Biopesticides should be identified and certified as environmentally acceptable tools and included in these programs.

• *Agricultural Research:* Agricultural research funding must be increased. In constant dollars, agriculture research is being funded at the same level it was in the mid-1960s. In 1939, 80 percent of the Federal budget went to agricultural research; today it's only 1.5 percent.

Only about $100 million of the Department of Agriculture's $1 billion research budget goes into biotechnology. The National Research Council also recently recommended greater support for research on biological controls.

Competitive Grants

The Department of Agriculture needs increased funds to support basic agricultural research in biotechnology at our nation's land-grant universities. Applied research is best conducted in the private sector. Federal research dollars should be directed toward identifying new opportunities for biological control.

There should be greater emphasis given to the competitive grants program if our nation is to succeed in making important new agricultural research discoveries. Competitive research program help ensure that our Federal dollars are directed to areas with the strongest research programs. New dollars, awarded to scientists on a competitive basis, will again make agriculture competitive for top scientific talent.

Let me emphasize allocating research dollars on a competitive basis. I am a firm believer in rewarding those people who get the results. My father used to tell me that "actions that get rewarded get repeated." So, let us make sure it is the desirable actions that get repeated.

• *Regulatory Process:* The existing regulatory structure is adequate to protect public health and the environment. Depending on the nature of the product, the U.S. Department of Agriculture, the Environmental Protection Agency and the Food and Drug Administration review and assess the safety and effectiveness of biopesticides, and their impact on food safety. New regulations are not needed.

Consideration, however, should be given to streamlining and accelerating the review process. For the most part, regulatory decisions have been delayed for political rather than scientific reasons. The regulatory agencies must include within their operating budgets programs devoted specifically to the efficient review of new biotechnology products. These programs should function independently of routine, day-to-day operations, focusing solely on registration of biopesticides.

Our regulatory agencies are being pressured to assure the public that there are no risks whatsoever associated with a proposed product. This pressure delays approvals, because there is no such thing as a risk-free society.

We must give our scientists and regulators the confidence and authority to review scientific data and make smart decisions about a product's safety and benefits versus risk.

• *Environmental Assessment:* In the area of risk assessment, there may be need for additional study and review. While science and history illustrate the safety and efficacy of biopesticides, it is important that the public and biotechnology skeptics are convinced that biopesticides and other products of biotechnology are safe.

Federally funded research in biotechnology risk assessment will build a data base of significant information, as well as will help build consumer confidence in biotechnology-derived products.

While industry has completed environmental impact statements and conducted research on the impact of biopesticides and genetically improved plants on the ecosystem, independent studies may be needed to substantiate private findings. There is, however, no need to delay the field testing and commercialization of new products resulting from biotechnology research. If we don't go forward with these field tests, we risk the competitive position of American farmers.

Research institutions, such as the Boyce Thompson Institute, would conduct risk assessment studies, which should include research and data collection in different parts of the country, on an array of crops, and in different climates. These types of tests should be conducted concurrently with existing industry and other studies, and should not delay our ability to bring environmentally compatible products to the marketplace.

Biopesticides are effective means of controlling agricultural pests in an environmentally acceptable manner. They hold the promise of reducing our nation's dependency on synthetic chemical pesticides, while at the same time allowing farmers to produce a reliable, high quality supply of food at a reasonable cost. U.S. agricultural policy should promote new technologies that offer agricultural production, efficiency and environmental benefits. It should also promote and offer incentives to farmers who want to adopt new technologies and farm practices to meet consumer demands.

PRODUCTS IN BIOTECHNOLOGY

(By Richard D. Godown, President, Industrial Biotechnology Association, Washington, D.C.)

Biotechnology consists of a variety of safe techniques for developing new products and improving microbes, plants, and animals. In agriculture, it has the potential to make farming more reliable, reduce the farmer's input costs, produce foods of higher quality, protect the environment through the substitution of biodegradable products for non-biodegradable products, and help developing countries feed their people.

Farming is a risky business. Weeds are always ready to compete with crops for moisture and nutrients. Insects and plant diseases take their toll. A late frost in spring or an early frost in autumn can destroy an entire season's produce. Too much rain can be just as devastating as too little. According to *The Economist,* at present a farmer in America's Midwestern Corn Belt has no defense against at least 50 insect pests and 50 crop diseases. And frost costs the world's farmers $14 billion a year. *(1)* Some of the problems faced by modern farming, such as unpredictability and sometimes unprofitability, can be solved by the use of biotechnology.

Until recently, agricultural innovation has focused on increasing yield. Today, agricultural researchers have other goals:

- *Reliability:* Genetic engineering has already produced plants that resist viral disease and microbes that protect crops from frost damage and insect pests. Protecting crops from the vagaries of nature can make farming an even more reliable business.
- *Cost Efficiency:* American farming has become capital intensive, often requiring large input costs in the form of seed, equipment, and supplies. Through genetic engineering, new crops and agricultural products are being developed to reduce the farmer's input costs and stabilize production. A resulting alteration in the use of agricultural chemicals is expected to have environmental benefits as well. New biotechnology-derived animal drugs will improve animal health and feed efficiency.
- *Crop Quality:* Biotechnology is being used to develop crops that are tastier, more appealing, and more nutritious. Genetic engineering is working to develop leaner animals that could produce meats lower in calories and cholesterol. Research is under way to improve the protein quality of a variety of crop plants.
- *Crop Diversity:* Genetic engineering may yield entirely new crops that will open new markets to farmers. For example, farmers may someday grow crops that produce high-value proteins and chemicals such as specialty oils.

In the developing nations, crop yield is still an important goal. Recent advances in agriculture and a decline in the rate of population growth have minimized the specter of famine for the time

being. But experts warn that the present abundance of food may be temporary. Southern Asia and Africa are particularly at risk.

According to Dr. Nyle Brady, Associate Administrator at the U.S. Agency for International Development, there is no way that Africans will be able to feed themselves utilizing existing agricultural technology; the only prospect for hope lies in the development of new technologies that fit their conditions. Only through biotechnology will it be possible to develop plants which can tolerate high salt conditions and conditions of high aluminum toxicity, for example.

New Foods and Non-Foods

According to a food biotechnology survey completed by the U.S. Food and Drug Administration (FDA) in 1987, 155 companies are working on more than 400 projects using biotechnology to improve foods. Although no one knows which of these new products will meet expectations and find their way to supermarket shelves, food technologists agree that biotechnology and other advancements will make novel products increasingly available over the next few years. Examples of some agricultural biotechnology products that are available or are expected to be available in the next 5 years are shown in Tables I and II.

TABLE I.—PROJECTED COMMERCIALIZATION OF SELECTED CROP/TRAIT IMPROVEMENTS

Crop	Enhanced weed control	Virus, disease, and insect resistance	Yield improvements	Quality improvements
Vegetables	1994/1995	1994/1995		
Oilseed and fiber crops	1994/1996	1995+/1998	1997/2000	1997/2000+
Cereals	1997+/1998	1998/2000	2000	2000+

Source: Industrial Biotechnology Association (1989).

TABLE II.—REPRESENTATIVE FOOD AND NON-FOOD BIOTECHNOLOGY PRODUCTS

Type of product	Current status
Microbial products used in food processing:	
Amylases for starch conversion	In use.
Chymosin for cheese making	Approval expected.
Polysaccharides for thickening agents	In use.
Flavors and fragrances	In use.
Genetically engineered crop plants:	
Disease resistant tomatoes	Field testing.
Insect resistant tomatoes	Field testing.
Herbicide resistant tomatoes	Field testing.
Controlled ripening tomatoes	Field testing.
Insect resistant cotton	Field testing.
Herbicide resistant cotton	Field testing.
Herbicide resistant corn	Field testing.
Virus resistant corn	Field testing.
Canola (oil rape) producing modified oil	Field testing.
Microbial pesticides:	
Insecticide active against coleoptera	Marketed.
Cotton fungicide	Marketed.
(A number of others are currently in R&D.)	
Animal drugs:	
Bovine somatotropin—milk production	Late stage R&D.

TABLE II.—REPRESENTATIVE FOOD AND NON-FOOD BIOTECHNOLOGY PRODUCTS—Continued

Type of product	Current status
Porcine somatotropin—leaner meat	Late stage R&D.
Ovulation hormones	Late stage R&D.
Pseudorabies vaccine	Marketed product.
Scours vaccine	Marketed product.
Bovine interferon/control of shipping fever	R&D.
Animal technology:	
Embryo transplant	In use.
Production of transgenic animals	Early stage R&D.
Diagnostics:	
Salmonella assay	In use.
Listeria assay	In use.
Pseudorabies detection assay	In use.

Source: Industrial Biotechnology Association (1989).

Food Safety

Some of the first applications of new biotechnology are coming in the area of food safety. Biotechnology's contributions to food safety stem from two fields of technological advancement. First, improved diagnostic methods are being developed to detect microbial and chemical contaminants in food. Second, safe biological pesticides will increasingly replace chemical pesticides associated with undesirable residues in foodstuffs.

In diagnostics, biotechnology has been used to develop quick, reliable tests to detect microorganisms and chemical contaminants that cause food poisoning. Some of these new tests use "gene probes," bits of DNA that bind to specific genes in food-poisoning microbes. Because each species has a unique complement of DNA, gene probes positively identify dangerous microbes, even if they exist in extremely small numbers in a food sample.

The U.S. Food and Drug Administration has approved probes for about a dozen food-borne pathogens. These probes are used in surveillance programs to protect Americans from food tainted by *salmonella* and other disease-causing microorganisms. Gene probes are replacing or complementing more cumbersome and time consuming methods of detecting pathogens in foods.

In addition to gene probes, scientists are using monoclonal antibodies to develop food safety tests. Antibodies are proteins the body produces to tag foreign invaders, such as microbes and microbial toxins, marking the invaders for destruction by the immune system. Each antibody binds specifically with a particular type of invader.

Monoclonal antibodies are identical antibodies produced in large quantities under laboratory conditions. Applied to food samples, monoclonal antibodies can be used to mark and identify harmful microbes and toxins.

According to the 1987 FDA survey mentioned above, scientists are using gene probes, monoclonal antibodies and other biotechnologies to develop 122 new tests to detect such food-borne microbes and microbial toxins such as *aflatoxin,* a natural toxin that sometimes contaminates stored grains. Another 27 tests are being developed for detection of food-borne chemical contaminants, such as

pesticide residues. Since these tests are more sensitive than current methods, they will permit the detection of smaller quantities of contaminants in food samples.

Biological Control of Pests and Weeds

Some biotechnology companies are working with a bacterial gene from *Bacillus thuringiensis,* or B.t., that produces a natural, environmentally safe protein which protects the plant from leaf-eating insects. B.t. has been used by home gardeners for over 50 years and has been demonstrated completely safe for human and animal consumption, but deadly to certain harmful insect larvae.

Unfortunately, currently available preparations of B.t. do not meet the needs of most commercial farmers.

These shortcomings are being addressed through genetic engineering. Strains that have enhanced toxin production are in field trials. The gene that codes for the insect toxin has been isolated and inserted into microorganisms that are environmentally more stable or have different habitats. These efforts are expanding the range and utility of microbial pesticides. In addition, some biotechnology companies have experimented with inserting the B.t gene directly into crop plants.

Viruses are also plant pests, and farmers have learned to live with between 5 and 30 percent crop loss each year caused by viral infection. In early experiments, however, genetically engineered tomato and tobacco plants have been made resistant to a viral disease that costs farmers as much as $200 million every year. Scientists hope to develop other viral resistant crop plants as well.

Research on genetically engineered herbicide tolerance involves a new class of broad-spectrum herbicides which are environmentally benign. Biologists have developed plants that tolerate glyphosate, for example, an herbicide that presents no significant risk to humans or animals and does not leave residues in the environment.

If more crops can be made compatible with the safer broad spectrum herbicides, farmers will be able to use these chemicals directly on emerging crop plants. Coupled with no-till agricultural practices, the farmer can control weeds with a single herbicide rather than the several now required. This has distinct promise for improved environmental control of weeds as well as reduced soil erosion. The net result is lowered input costs for the farmer relative to existing technologies.

Agricultural Microbes Affecting Plant Growth

Myriad bacteria and other microbes live on plants and in the soil. Most are harmless, and many are beneficial to crops. Some microbes, for instance, are natural fertilizer factories. An entire family of soil bacteria, the *Rhizobia,* convert nitrogen from the air into a form that plants can metabolize for plant growth. For more than 50 years, farmers have treated soil with these bacteria to encourage growth of crops like peas, soybeans, and alfalfa. Biologists are using genetic engineering to enhance nitrogen fixation in these bacteria. In addition, the genetic factors that control the plant-microbe symbiotic relationship are being elucidated. The aim of this

research is to see how the nitrogen fixation capacity of these microorganisms can be extended to non-legume crop species.

Other kinds of bacteria play a role in frost damage that can ruin crops. These bacteria produce a protein which serves as a nucleus for ice crystal formation when temperatures dip below freezing. Noting that some forms of the bacteria do not possess this characteristic, biologists have developed a way to remove the gene that produces the ice-nucleating protein. They hope that the resulting non-ice nucleating bacteria, when spread on crops, will prevent frost from forming on the plants even at temperatures several degrees below freezing.

Products for Animal Agriculture

In addition to developing improved plants and microbes, biologists are using biotechnology in livestock agriculture. Many of the achievements of biotechnology in human health care have comparable applications in prevention and treatment of animal disease and in promotion of animal growth and efficiency.

A major problem in this area of agriculture is the loss of animals to infectious disease. Genetically engineered alternatives to traditional vaccine preparation which are safer, more effective, and have fewer side effects are under development and some vaccines have already been approved for marketing.

Using biotechnology, scientists are better able to disarm the infectious organism used in vaccine production. Genes essential to the disease process can be removed from viruses used in a vaccine, rendering the viruses harmless. Or one or more genes may be removed from a virus and used to make proteins normally found on the virus' surface. In this approach, scientists hope to be able to use the surface proteins to stimulate an animal's immune response to the virus, without injecting the virus itself into the animal.

Safer, genetically engineered vaccines against a disease called swine pseudorabies are commercially available. There are both monoclonal and recombinant vaccines against scours, a diarrheal disease that afflicts newborn animals.

Scientists also use genetic engineering to develop new therapies, as well as to promote animal growth and efficiency. In these uses of genetic engineering, the genes for certain animal proteins are spliced into bacteria. The bacteria are grown in fermentation vats, where they produce large quantities of the proteins. The proteins are then purified and administered to animals. Among the therapeutic animal proteins, scientists are studying genetically engineered bovine interferon and interleukin, natural components in the immune system of cattle. These proteins may prove to be effective against shipping fever, a viral disease that attacks cattle during transport, causing an estimated $250 million in losses each year.

Several companies are engaged in widespread testing here and in Europe of bovine somatotropin, or bST, a naturally occurring protein that can be produced commercially by genetically engineered bacteria. When administered to dairy cows, bST enables them to convert feed to milk more efficiently, thus lowering the farmer's feed cost per gallon of milk produced, particularly desirable now,

with the cost of animal feed rapidly escalating as a result of last year's drought.

Published studies show that administering bST has caused no health problems in cows. Testing continues until final Food and Drug Administration approval of bST as a safe product for cows. Published studies also show that bST presents no health risk to consumers, and the Food and Drug Administration has already approved the sale of milk and meat from bST-treated cows during this testing phase.

Scientists are also using genetically engineered bacteria to produce a naturally occurring porcine protein that promotes rapid growth in pigs. The aim is to reduce the time, and thus the cost, of raising pigs until they reach market size. Early experiments show that the protein also lowers the fat content of the pork, making the meat lower in calories and cholesterol, and thus more healthful. This will result in meat products that are more in accord with current dietary guidelines that urge lower fat in the diet.

One of the newest developments on the animal side of agriculture is in the field of transgenic animals. Transgenic animals are animals whose genetic heritage has been altered so as to contain a single gene, or at most a handful of genes, from a non-parent animal. The goal of transgenic animal technology is to produce animals with improved characteristics, such as disease-resistant chickens and pigs that produce leaner pork.

According to an excellent report by the American Farm Bureau Federation entitled, *Animal Patents: Agriculture's Perspective,* animal products currently account for half of all U.S. agricultural revenues. Genetic improvements of animal breeds is currently accomplished through selective matings of superior examples within a breed type or between breed types. It is a slow process and is limited by the female's markedly small reproductive capacity. Using gene transfer technologies, we may be able to achieve more genetic improvement in a single gestation period than has been possible using classical genetic selection over a period of decades.

We expect that the transferred genes will confer increased growth performance, disease resistance, and certain reproductive traits which collectively will lower input costs and produce a more healthful product for the American consumer. The rapid development of recombinant gene transfer in animals will also offer livestock agriculture the opportunity to develop totally new products. For example, molecular farming may include the production of protein pharmaceuticals such as insulin, interferon, and blood clotting factors in milk produced by dairy cattle and in eggs produced by chickens. Products such as insulin can then be recovered from the milk, the milk discarded, and the insulin purified and used by diabetics.

Food Enzymes and Processing

There is significant research directed towards the improvement of enzymes useful in food processing as well as for corn starch transformation. Much of the agricultural output from U.S. farms is further processed into food or other high value added compounds.

In that biotechnology will improve these processes or develop new ones, it will ultimately improve the profitability of farmers.

Research and Extension Efforts

U.S. companies presently hold the lead in biotechnology, but whether or not we will continue to be preeminent depends largely on whether Federal funding of basic scientific research at our universities is adequate. If it is not, then the foundation on which our industry builds will be shaky, and our ability to compete in international markets will be reduced. Furthermore, without adequate funding of university research, our colleges will not be able to train sufficient numbers of scientists to take the jobs our industry is producing.

Policy Recommendations

IBA believes that the Federal Government needs to increase its role of funding basic, peer-reviewed agricultural research because of the great impact of agriculture on the economy of the nation. Unfortunately, basic agricultural research needs are not easily comprehended by the general public.

Conventional approaches to research support given to agriculture can serve as a foundation on which to build a stronger, competitive, peer-reviewed system. With the arrival of the revolutions in plant and animal molecular and microbial biology and similar dramatic changes in biotechnology, these conventional approaches must be updated and revised to address the changing needs of research in the 1990's and beyond.

Without adequate funding, however, grant programs are limited in their benefit. For years, Federal funding for agricultural biotechnology has been inadequate. In fiscal year 1987, for example, total Federal funding for biotechnology research was $2.7 billion. Of that, $2.3 billion was allocated to the National Institutes of Health specifically for research and development related to human health needs. Only $84 million, or 3 percent, was directed toward the field of agriculture. Not only does this inhibit the rate of scientific discovery, but the lack of sufficient funding prevents us from training the necessary scientific manpower to create and capitalize on new discoveries in molecular biology as applied to agriculture.

As Congressman George Brown (D–CA) has noted, USDA funding for agriculture research is still at 1967 levels in constant dollars. USDA research funding at universities is the second lowest of the six major Federal agencies which fund research. And USDA's basic research funding is the lowest of these agencies, both in total dollars and as a percentage of overall agency research funding.

Private industry is the largest single source of agricultural research funding, conducting about $2 billion of research last year, of which about $150 million was devoted to agriculturally related biotechnology research. But the private sector, constrained by shorter-term profitability needs, cannot be expected to fully fund basic research. And even in applied research, funding is product-oriented, is 95 percent in-house, and cannot fill all of the research needs of the diversified agriculture sector. *(2)*

IBA supports the National Academy of Sciences' report, *Agricultural Biotechnology: Strategies for National Competitiveness,* which called for increasing Federal research support in agricultural biotechnology to $500 million per year for competitively awarded research. We feel this level is not excessive, but is in line with the pace of developments in the technology and is necessary to maintain our competitive edge.

Conclusion

The biotechnology industry is seeking to endow plants and animals with a small number of selected traits to improve agriculture. Recombinant DNA will shorten the time period that is required to develop these traits. It is important to recognize that the agricultural community has continually developed new traits through conventional breeding; what biotechnology has to offer is faster development and a wider range of possibilities by designing a given trait.

Biotechnology offers tremendous potential benefits to society; therefore, serious consideration should be given to increasing funding for research, providing more comprehensive intellectual property protection, and creating more financial support and educational incentive to encourage graduate study in these fields.

America's research enterprise has to be considered in partnership terms rather than government and industry working toward their own ends. In this way improved agricultural technologies can be researched, developed, and realized to the greater benefit of the American public and the world at large.

References Cited

(1) "The Biotechnology Survey." The Economist, April 30, 1988.
(2) Brown, George, Jr. "Getting to the New Age in Agriculture," October 21, 1987.

IMPLICATIONS OF PLANT GENOME MAPPING

(By Wm. Hugh Bollinger and Dale J. Hansen, NPI, Salt Lake City, Utah)

A major technological breakthrough in plant genetics has recently emerged. It is referred to as plant gene or genome mapping and allows for the identification of the actual genes responsible for controlling overall physiological growth, development and productivity in virtually any plant species. These new methods could eventually have a major impact on agriculture, horticulture and the American food system. To facilitate and expand this technology, the U.S. Congress should establish several targeted objectives to meet national goals. Reorganization of some existing governmental programs and encouraging collaboration between the public and the private sectors could greatly facilitate the incorporation of gene mapping into the national primary production industries.

The Nation has barely scratched the surface of the many potential benefits the tools of biotechnology could bring to agriculture.

Our biotechnology strategy must focus on solving important scientific, production and quality issues while effectively using the funds and institutional structures available to support advanced research. Thus far, governmental programs have been short-term, ad-hoc approaches which have not addressed the long-term requirements of integrating the new technology into the nations agricultural and food system.

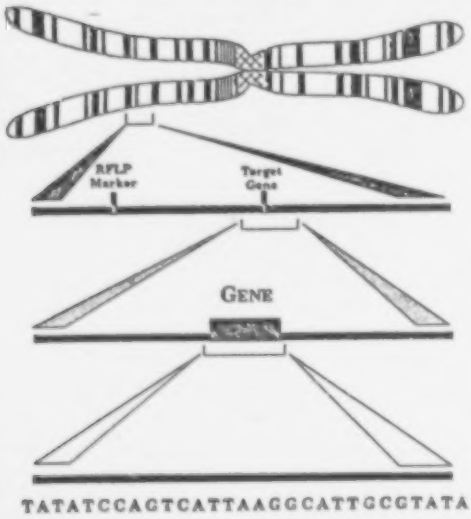
Gene Mapping Background

Since the discovery of the structure of DNA numerous technical advances have occurred which include the ability to extract and manipulate the molecule, the ability to replicate identical genes in bacterial cells, and methods to understand the detailed organization and control of coded genetic information. During the past two decades this ability to manipulate DNA has progressed from being a laboratory curiosity to becoming a practical methodology in every discipline involving the life sciences. Leading countries of the world, including Europe, Japan, Australia, and the United States, are all striving to utilize the new methodologies to improve their agricultural base and fuel industrial processes.

Although relatively new, plant genome mapping has emerged as one expression of the new DNA methods which will make important contributions to crop improvement. Physical genetic mapping as defined here is the determination of plant genome organization. In the broadest sense physical mapping has historically meant the identification of chromosomes and of physical traits regulated by them. In the narrow sense and as discovery continues, a completed physical map of the genome will contain the complete DNA sequence along with descriptive function of each individual gene.

This review for the U.S. Congress will cover the various aspects of genome organization including traditional approaches to mapping through plant genetics, DNA markers, and sequencing genomic DNA. These levels of genome organization are illustrated by the accompanying diagram.

Levels of Gene Mapping



Mapping Genes to Whole Chromosomes

RFLP Genetic Linkage Mapping

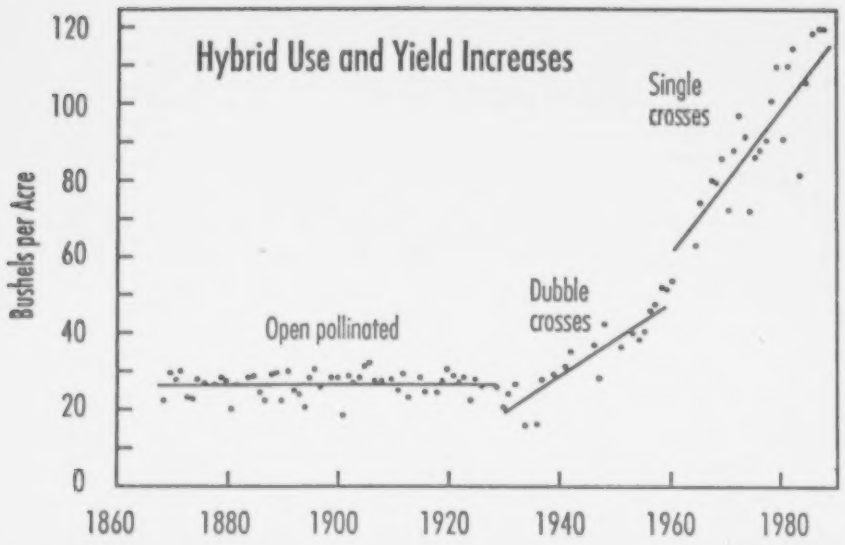
Physical mapping of DNA Fragments

Sequencing of DNA Fragments

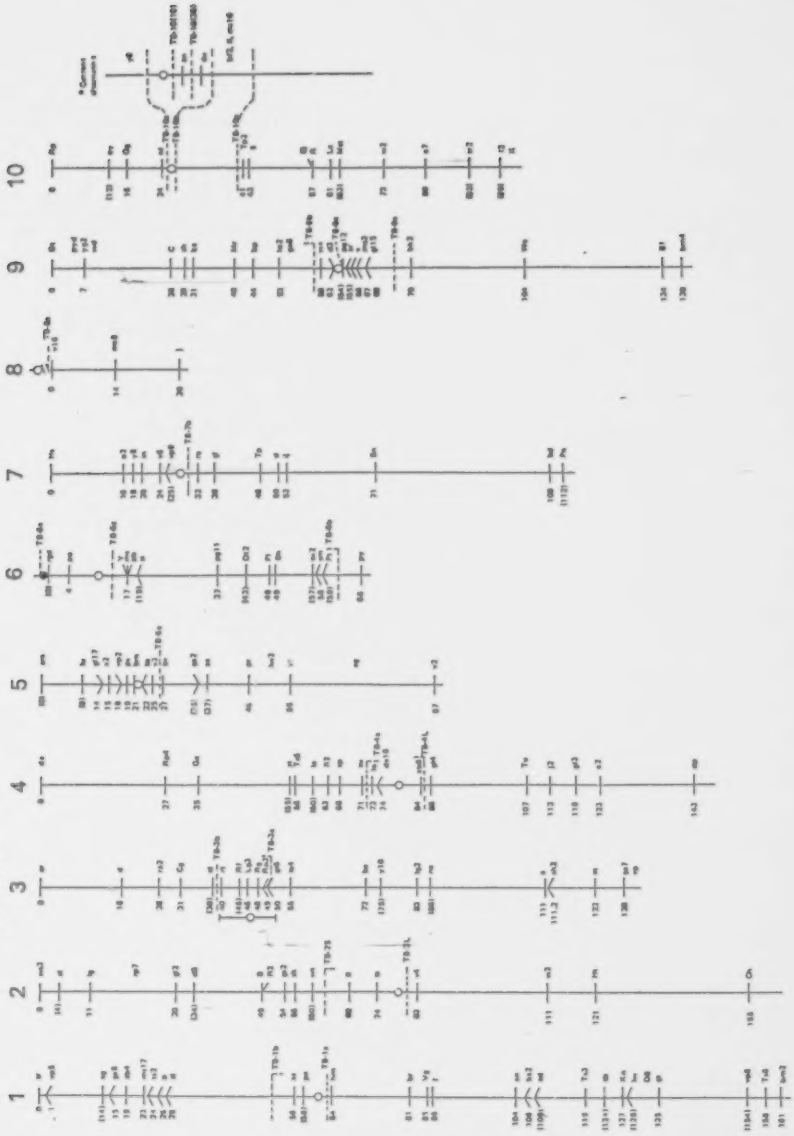
We will document recommendations concerning maintaining a leadership position for the United States and logical ways of organizing the work at lowest cost.

Plant Breeding Approaches to Genome Mapping

Genetics as a scientific discipline began with the discovery by Gregor Mendel that plant traits can be inherited from parents when controlled crossings are made. From 1860 forward plant geneticists have been making hybrids and increasing crop performance, diversity and product outputs. An illustration of the impact genetics has had on corn yields is shown in the illustration below.



Early cytological studies permitted the identification of chromosomes leading to sophisticated breeding strategies which have produced a working physical map in a few plant species. Even though DNA could not be directly measured or the precise genes identified, mutant genes that modified the physical appearance, the phenotype, were used to create more detailed genetic maps. The corn map created by the early methods, is shown in Figure I to illustrate the progress prior to molecular DNA mapping technology.


LINKAGE MAP OF MAIZE
April 14, 1976
10
9
8
7
6
5
4
3
2
1

This map, while useful in academic studies, was of limited commercial value since most of the genetic markers were derived from genes causing mutations. Until the advent of advanced molecular biological approaches the power of the actual genes involved in plant production and product output remained obscure and unavailable to the plant breeder.

Restriction Fragment Length Polymorphism (RFLP) Technology

Use of restriction fragment length polymorphisms (RFLP's) as genetic markers developed during the 1980's and vastly expanded the understanding and potential of physical gene maps. RFLP's are DNA based genetic markers that occur throughout the genome but which have no known biological function. DNA-based probe mapping has all the advantages of the above methods in addition to numerous other advantages that will be discussed.

The term RFLP refers to fragments of DNA created when exposed to specialized enzymes (restriction endonuclease) that cut the DNA at defined nucleic acid positions. A single endonuclease will cut DNA into numerous pieces of varying sizes which can then be separated based on molecular weight by using gel electrophoresis. Since there are many different restriction enzymes that cut at distinct positions, an almost unlimited number of DNA fragments can be created. DNA isolated from different individuals and cut with a restriction endonucleases give a distinct pattern from each other.

Because DNA is a double stranded macromolecule held together by hydrogen bonding, it can be separated by denaturing techniques such as heating. When conditions are favorably altered to allow the two strands to come together, complimentary DNA segments will recombine. This principle, termed DNA hybridization, allows short segments of DNA, often about 1,000 base pairs in length, to be isolated and used as marked probes. These marker probes are usually detected by the incorporation of a radioactive label. Since the number of marker probe segments that can be created is essentially unlimited, one can begin to identify RFLP segments which cover the entire plant genome. By analyzing numerous second generation progeny, RFLP fragments can be assigned chromosomal locations based on DNA rearrangements during sexual recombination.

Mapped DNA probes have several advantages over other methods of physically mapping chromosomes, (i) they are available in almost unlimited numbers and can be selected throughout the genome, (ii) it is unnecessary to alter commercially useful germplasm since the probes are copies of short DNA segments already present in the plant, (iii) in species with large numbers of DNA polymorphisms they identify and distinguish all germplasm sources, (iv) destructive sampling is unnecessary since small amounts of tissue are sufficient for determining the genotype, (v) multiple allelic forms can be quickly determined, and (vi) multiple loci contributing to complexly inherited traits can now be distinguished. The following table illustrates a number of multiply inherited genes known to affect various end-use qualities in wheat, for example.

ENVIRONMENTAL INFLUENCE ON IMPORTANT END-USE QUALITY TRAITS IN WHEAT

Trait	No. of genes	Environmental influence
Physical quality:		
Hardness	3 genes	Moderate.
Color	3 genes	Moderate.
Kernel size	Many	Large.
Test weight	Many	Large.
Flour yield	Many	Large.
Biochemical quality:		
Protein percentage	Few-many	Large.
Absorption	Many	Moderate.
Mixing tolerance	Many	Large.
Loaf volume	Many	Large.
Crumb grain	Many	Large.
Crumb color	Many	Moderate.
Loaf symmetry	Many	Moderate.
Gluten strength	Few	Moderate.
Pasta quality	Many	Large.

Source: Office of Technology Assessment, 1989.

By breeding plants with diverse phenotypic characteristics and making both genotypic and phenotypic measurements, data can then be sorted to associate (link) RFLP markers with genetic characteristics of interest. Once linked, the markers can be followed in subsequent generations thereby eliminating environmental effects on phenotypic expression and permitting genotypic determinations at the seedling stage. Until the advent of genetic DNA mapping, it was very difficult to make progress in improving complex multigenic traits since their heritability is close to zero. However, progress has been achieved very slowly since this required evaluating the performance of a large number of progeny over many years. With RFLP's, rapid progress can be made in identifying complex traits and following their inheritance. This may be particularly important to food quality components since they are normally controlled by many genes inherited complexly. Such characteristics as yield, flavor, fragrance, and nutritional components are just a few examples of complexly inherited attributes in plants.

Plant Genome Mapping—Existing Status

RFLP based genetic mapping is a powerful new approach that provides an opportunity to view the pedigree of an organism based solely on its DNA. Since the development of this approach for plants did not begin until the 1980's, vast scientific, technological and commercial opportunities lie ahead. Chromosome maps containing DNA probe sites and linkage distances are the most advanced for corn, with nearly 900 probes available from several sources. The corn linkage map developed in our laboratories is shown in Figure 2. The numbers represent information relative to each DNA probe that was used to construct the genetic map.

Maize Genetic Linkage Map

Tomatoes probably have the next largest number of DNA probes available with approximately 300 to 400 from all sources. Due to lack of genetic variation in this plant, useful probes are obtained by crossing commercial cultivars with wild tomato relatives. Experience in our own laboratories indicates that about 5 percent of the probes are useful for detecting genetic loci within commercial cultivars. This makes both the number and use of existing probes somewhat limiting unless commercial cultivars contain germplasm from other related species. Tomatoes, however, may represent the first American food crop to commercially benefit from the new gene mapping methods.

Gene mapping development work is now in progress at numerous laboratories on a number of crops. In addition to those laboratories involved in map development, an even larger number of laboratories is starting to utilize the maps for crop improvement. Nearly every major agricultural corporation appears to be evaluating this technology for product improvement applications.

Plant Genome Sequencing

The ultimate goal of physical gene mapping is to construct a map containing the entire DNA base-pair sequence of important agricultural crop plants. This would permit the identification of both functional and non-coding genes as well as regulatory sequences controlling them. However, it may be some time before the DNA sequencing goal is achieved because of the effort required to reach such an objective. The DNA content of important crop plants ranges widely, but in most cases is larger than the human genome. Sequencing the more than 3 billion basepairs of the human genome is expected to take 5 more years and may cost upwards of $1 billion. Because of the enormity of the task, one research scientist utilizing a DNA sequencing machine costing approximately $100,000 can sequence and verify approximately 1,000 base-pairs per day, and numerous laboratories worldwide most likely will be involved. At this time, the value of this detailed type of sequence data to crop improvement is questionable since such information is not required to construct successful hybrids once the DNA probes and genomic maps are available.

After one genome has been sequenced, the major work of determining coding genes along with their function must begin.This part of the task is larger than the actual DNA sequencing work. It will then be possible to study regulation of individual genes as well as to study different sequences between genetically distinct individuals that cause allelic variation. It should be remembered that most genes will not have a "value" from a practical or commercial perspective.

Should the U.S. Government choose to sequence one or more plant genomes, care should be taken in choosing the first species which will then provide substantial information toward sequencing others. Two plants currently have enough information and advantages to support a DNA sequencing project; *Arabidopsis thaliana* and corn *Zea maize.* Both have genetic linkage maps available, both have diploid genomic organization, and both have been investigated in considerable detail at the molecular level.

Arabidopsis has many useful features as an experimental organism since it completes a life cycle in 5 weeks, produces numerous seed, has the smallest known genome of any angiosperm, and has been widely studied in leading academic research laboratories. Corn, although a much larger genome than *Arabidopsis,* is the most widely grown U.S. crop and is being investigated by a large number of laboratories. Considerable pedigree information is available both in universities and the private sector and large germplasm resources are available. Detailed information concerning individual chromosomes, and the numerous RFLP probes already available will make it possible to move forward with only modest additional characterization.

Applications of Plant Genetic Mapping

• DNA gene mapping can play a pivotal role in agriculture, horticulture and the food system. Because plants contain such large numbers of important production and quality controlling genes, methods are needed to monitor their inheritance. DNA probes are the only practical methods available for such monitoring.

• Genetic mapping can facilitate the development of new plant cultivars with substantially superior traits faster that was previously possible. This will occur through:

(a) Germplasm organization;

(b) Identification of heterotic groups;

(c) Identification of loci controlling quantitatively inherited traits;

(d) Identification of superior alleles;

(e) Monitoring the simultaneous inheritance of superior alleles for several quantitative traits;

(f) Reduce testing of potential plant cultivars that do not have the desired traits; and

(g) Overcome obstacles of environmental interactions that are difficult to monitor.

Genetic mapping can advance the concept of "Crops as Factories" to produce new desired commercial end-products which could not be previously produced.

Genetic mapping provides an analytical tool for identifying plant materials. This will be useful for raising food quality standards.

Genetic mapping can provide a method for defining ownership of elite plant materials since the segments of DNA that constitute the genome can be defined as unique genetic fingerprints for a given new variety. This will facilitate the patenting of new plant discoveries and also permit Plant Variety Protection legislation to be rewritten and more clearly defined.

Genetic mapping can facilitate sequencing of an entire plant genome by providing known starting points.

Genetic mapping can allow the identification of loci which control or encode genes for specific traits, especially complex traits regulated by multistep biochemical pathways.

Policy Recommendations

- Construction of complete linkage maps with DNA probes for major agricultural and horticultural plant species must be undertaken.
- Commercially available sources of the probes, equipment, supplies and support must emerge from the private sector.
- Development of national standards for DNA probes and genome maps will be required to accelerate their utilization in scientific and commercial applications.
- Correlation of the probes with plant genes controlling important traits of interest must be determined.
- Commercial development of new superior cultivars must occur.
- The technology to reduce the cost and shorten the analysis time must be extended.

Extension of the technology to new crops and plant byproducts to help diversify American agricultural production must be initiated.

Development of advanced computational hardware systems and software is needed to store, retrieve and manipulate the vast data produced from plant genome mapping efforts.

Redefinition of regulations and guidelines for issues of commerce including plant and seed labeling, quality, and property issues must be considered.

Recommendations to the U.S. Congress

If the United States is to maintain the lead in genetic mapping technology of plants, government support must be expanded. Needs listed above must be met to achieve the potential of this technology. U.S. industry must compete with countries such as Japan and the European Economic Community where the governments have already determined plant gene mapping to be a fundamental pioneering high technology.

Government support for this technology would most efficiently be realized through sponsored collaborative grants to universities and industry. This would be particularly beneficial in regards to the advanced computational requirements for plant genome mapping.

Division of the work effort between universities and industry could be expeditiously done as follows:

Industry should focus on development of linkage maps and probe sets followed by quality production and commercial supply of reagents and materials to advance the mapping efforts.

Universities could contribute substantially to the development of superior mapping methodology, association of probes with loci, DNA sequencing work to locate genes, and training students in the methodology. Both universities and industry should cooperate to apply independent accomplishments to the production of superior new cultivars to agriculture and horticulture as well as create novel plant products.

Government needs to take an active role in redefining legislation concerning plant varietal protection. Genetic mapping technology makes part, if not much, of the existing legislation obsolete. However, because the technology is new there is sufficient time to study required changes and implement them in an expeditious manner.

Plant genome sequencing at present would be very expensive, even by government standards, and perhaps of limited commercial value in plants. Plant genome sequencing should be approached slowly, perhaps beginning with one plant and then continuing systematically from crop to crop as gene maps become well enough developed and as sequencing methodology improves.

Government should establish specific goāls to meet national needs, such as the creation of plant varieties which require less chemical inputs for their productivity, which will lead to the creation of new crops and improve the nutritional qualities of existing food crops, and which would expand efforts to incorporate genetically improved plant varieties in sustainable agricultural production systems.

BIOTECHNOLOGY: RISK ASSESSMENT RESEARCH

INTEGRATING BIOTECHNOLOGY INTO AGRICULTURAL SYSTEMS: THE NEED FOR MORE EXPERIMENTAL AGRICULTURE AT THE FARM LEVEL

(By Fred Gould, Department of Entomology, North Carolina State University, Raleigh, North Carolina)

Some people consider agricultural biotechnology to be antithetical to "sustainable agriculture"; others consider biotechnology as essential in developing sustainable agricultural systems. It could be either of these, depending on how we integrate this technology into existing agricultural systems.

If we define biotechnology broadly as the use of biological processes to develop products, agriculture has always used biotechnology. When new biological techniques such as quantitative genetics, artificial insemination, and crop hybridization were developed, they were incorporated into agricultural systems by industry, departments of agriculture, and farmers. Sometimes the incorporation of a new technology went smoothly, while in other cases, it had disruptive effects on the existing agricultural system.

The more abrupt the introduction of a new technology, the less chance there is to carefully integrate it into the existing agricultural framework. The unanticipated negative effects of the "green revolution" on Third World agriculture demonstrate the need to proceed cautiously when introducing powerful and exciting new approaches to complex systems. In retrospect, we can see how attention to ecological and social aspects of Third World agriculture could have made the green revolution less tumultuous. It has been said that new developments in biotechnology will revolutionize American agriculture. Whether the end product of such a revolution is better or worse for the American people will depend in part upon the way we integrate these new technologies into agriculture.

The approach we are currently taking generally involves having the USDA and land grant universities do very basic work in molecular biology and genetic engineering. Results of this research are made available to industries which use this knowledge in developing products. The type of products developed by industry and the way they are marketed is generally determined by relatively short-term profit analysis. Little effort has been made to assess the long-term impact on society of alternative products or alternative use patterns for these products. If we continue with this approach and a long-term problem develops, fingers of blame will be pointed and public money will be poured into corrective measures. It may be possible to avoid long-term problems and expensive corrective measures if we assess our long-term goals before products of new biotechnologies become embedded in our agricultural systems. De-

termining whether a product of biotechnology will help us achieve these goals cannot be totally addressed in the laboratory. There is a need for extensive field experimentation.

Premise of This Brief

It is the premise of this brief that (1) the USDA–ARS and land-grant universities should be supported to do proactive, applied research that will promote the development and use of agricultural biotechnology in ways that will offer maximum long-term environmental and societal benefits, (2) the farm bill could structure certain subsidy programs in ways that would promote interaction between farmers and researchers in testing innovative biotechnology products.

The American farmer has always been noted for being innovative, but current economic constraints hamper experimentation at the farm level. Legislation that offered incentives for innovative, ecologically sound experiments at the farm level could yield information inaccessible to most research scientists.

A model for such legislation exists in a successful excess allotment program for tobacco farmers who do cooperative work with experiment stations. The tobacco quota program allows a farmer to overproduce on his acreage if the excess crop is going to be used by any publicly owned agricultural experiment station. Without this provision, the excess crop would be penalized or held over until the following crop marketing year. A more general program that encompasses other crops and larger acreage is feasible.

To present the tangible benefits of such an approach, I will focus the rest of this brief on a description of how such a program could be used to develop ecologically sound insect pest management programs that utilize genetically engineered crops. I would like to emphasize that this general approach *can be used with other biotechnology innovations and even with agricultural innovations that do not involve biotechnology.*

Problems With Current Pesticides

Currently, synthetic pesticides serve as one of our major tools for the control of agricultural pests. Three major problems attributed to conventional pesticides are:

(1) Negative effects on humans and wildlife;

(2) Destruction of natural enemies of the target pests; and

(3) Rapid pest adaptation to the pesticides.

While it is relatively easy to see the significance of problems 1 and 2, the significance of rapid pest adaptation to pesticides is less straightforward.

In terms of conventional pesticides, it sometimes takes pests less time to adapt to a pesticide than it takes scientists to assess the pesticide's chronic effects on humans and ecosystems (e.g., Colorado potato beetle adaptation to pyrethroid insecticides). Even if pest adaptation is not quite that fast, it may still cause changes in the classes of pesticides used, leaving environmental scientists playing a game of catch-up regarding risk assessment.

Another effect of resistance development is the use of higher doses of pesticides to achieve the same level of control. This is

costly for farmers and can increase off-target effects. In the 1940's and 1950's, synthetic chemists thought they could always stay ahead of resistance by coming up with new chemical classes of pesticides. We are now faced with a situation in which some pests, like the Colorado potato beetle, cotton bollworm *(Heliothis virescens),* and diamondback moth are achieving resistance to all available pesticides. Some may see the lost efficacy and use of these toxic pesticides as a benefit, but it is likely to have a severe negative impact on agriculture.

Benefits and Possible Problems With Use of Genetically Engineered Crops

The development of genetically engineered crop cultivars that produce toxins internally should lead to reduction in aerial and ground applications of conventional pesticides while maintaining agricultural productivity. Compared to conventional pesticides, these internally produced toxins are less likely to result in problems 1 and 2 because of their initial containment in plant tissues, their low overall quantity, and their probable short persistence in the environment. The social and environmental benefits from reduction in problems 1 and 2 are significant. Any environmental assessment of pesticidal, transgenic plants must weigh these benefits against risks such as transfer of pesticidal properties to weedy relatives of crops (e.g., sorghum to Johnsongrass) or to the native flora.

In terms of problem 3, pesticides produced in transgenic plants are a priori no less likely to face adaptation by pests than synthetic pesticides (Gould 1988a,b). The fact that these internally produced toxins are less likely to cause negative environmental effects does not eliminate societal concern regarding pest adaptation. If pesticidal plants are viewed as a reprieve from the problem of off-target effects of conventional pesticides, we want this reprieve to last as long as possible. The number of toxin types that will be produced by transgenic plants in the next decade is likely to be limited (see Proceedings of the recent Boyce Thompson Meeting, July 1988). If pesticidal plants are developed and used in a way that leads to rapid pest adaptation, the efficacy of these plants will be lost and agriculture will be pushed back to reliance on conventional pesticides with their inherent problems.

Even if new toxin genes are discovered that can be engineered into plants to replace outmoded toxins, it is not certain that the new toxins will be safe if they are produced in fruits (e.g., apples, peaches) or vegetables (e.g., broccoli, lettuce) that are consumed. When a toxin gene that is safe for consumption is placed in large acreages of forage and fiber crops in addition to crops consumed by humans, it is likely to be lost more rapidly to resistance in the target pest (Gould 1989, Proc. Boyce Thompson Institute Conference on Novel Pest Management Techniques, D. Roberts (ed.), B.T.I. Publisher, July 1988) and may be replaced by a new, but less safe toxin gene.

I would like to address the question of whether there are any feasible, alternative approaches in development and use of pesticidal, genetically engineered plants that would lead to a longer reprieve from reliance on conventional pesticides. I will discuss how the

farm bill could be used to encourage development and testing of these alternative approaches. As a specific example, I will consider plants being engineered to produce various types of B.t.-endotoxins which are toxic to caterpillar, beetle, and/or fly species, but appear to be safe for humans at low doses.

Current Approaches in Developing Genetically Engineered Plants

Currently, the genetic engineering approach being used by industry to develop pesticidal plants involves the splicing together of two segments of DNA. One segment of DNA comes from *Bacillus thuringiensis* and contains the specific code for δ-endotoxin. The other DNA segment that is spliced in front of the specific coding segment is called the promoter or regulatory DNA segment. It "instructs" plant cells to initiate the production process that leads to internal synthesis of the δ-endotoxin.

The combination of a regulatory sequence of DNA molecules and another sequence that contains the code for building a specific protein is not an invention of genetic engineers, it is the normal way that plant and animal genes are set up. Some normal genes have regulatory sequences that "instruct" all cells in a plant or animal to initiate production of "their" coding sequences during every second that the cell is alive. These are called constitutive promoters. Other types of regulatory sequences instruct cells to initiate production only under certain environmental conditions (e.g., when the organism is experiencing heat stress). These are called inducible promoters. A third type of regulatory sequence instructs only certain types of cells to initiate production (e.g., humans have genes for producing digestive enzymes in intestinal tissue as well as muscle tissue, but the regulatory sequences only initiate production of these enzyme when they find themselves in the cellular environment of the intestinal cells). These regulatory sequences are called tissue-specific promoters.

To date, the pesticidal plants headed for commercialization have been developed using constitutive promoters. This means that theoretically all cells in a plant should be producing the toxin at all times (see Benfey and Chua 1989). In terms of pesticidal activity, this means that any insect feeding on any part of the plant at any point during the growing season ingests the toxin. This might be an optimal approach if a crop needed protection of all parts all the time, but often this is not the case (Gould 1988a). Some pests occur at low levels in most years; other pests only cause economic damage in one of their two to six generations per season.

It is important to realize that selection pressure on pest populations to adapt to a toxin is similar, whether a plant causes 95 percent mortality of a small or large insect population. Years ago, before the development of Integrated Pest Management, farmers used to spray crops on a calendar schedule, whether pest numbers were high or low. Now, field scouts can assess levels of infestation to determine whether or not pesticide treatment is necessary. This approach should slow down the rate at which pests adapt to a pesticide. With constituitively expressed toxin genes in a plant, the farmer will be forced into the prophylactic control approach, be-

cause he or she must buy seeds before pest abundance can be forecast. If seed of pesticidal cultivars is not too expensive, most farmers will buy this seed for insurance purposes. With a pest that outbreaks every 10 years, a pest population could adapt to the pesticidal plants before the toxin ever has an impact on yield.

Alternative Approaches in Developing Genetically Engineered Plants

How do we alleviate this problem? A number of strategies are possible. If we restrict ourselves to the currently available plants that have constituitive expression, strategies must be at the level of germplasm deployment. The simplest approach with *some* crops may be to sell mixtures of seed with some seed expressing the toxin-coding gene and some lacking this gene. Planting a 50:50 mixture of such seed should reduce the rate of insect adaptation by two-thirds or more (Gould 1988). In crops where damage to one seedling is compensated for by extra yield in neighboring seedlings that no longer have to compete with it, overall yield losses may be small and farmers will never risk loss of an entire crop to the pest.

In many cropping areas, extension agents know that some fields are at higher risk of pest damage than others. Soil type, date of planting and irrigation systems can influence the abundance of southern corn rootworm, corn earworm, and Hessian fly, respectively. It may be possible to limit the use of pesticidal cultivars to high risk fields within a farm or county.

In developing genetically engineered plants, hundreds or thousands of transformed plants are screened for toxicity. Some plants do not express the gene at all some have low to moderate expression, and a few have very high expression. The plants with the highest expression are the prizes and plants with low or moderate expression may even be discarded. We rarely consider the fact that plants with low or moderate toxin production may be capable of reducing pest populations below economic damage levels while limiting selection for pest adaptation. Details of how low or moderate levels of the toxin affect the pests' fitness are essential in predicting rates of adaptation. As an example, when a pesticidal plant just slows down the growth rate of a pest, the pest is exposed to negative effects of predators and weather factors for a longer period of time. Additionally, the crop has a chance to "outgrow" the pest. In the case of pests that have 4–5 generations per season, slowing growth and reproduction by even 20 percent could eliminate the last and often most damaging generation. Unfortunately, field research in this area is yet to be done. The experiments will require large acreage and a number of seasons.

If we do not restrict ourselves to the currently used constituitive promoter sequences, we have a number of other options in developing pesticidal plants. These options involve the use of tissue-specific promoters and inducible promoters. In a number of crops (e.g., tobacco, soybean, corn), some tissues are more sensitive to damage than others (e.g., feeding on older soybean leaves causes less yield loss than an equivalent amount of feeding on partially mature beans). Engineered plants in which the toxin is only expressed in sensitive tissues could theoretically protect the plant without se-

22-829 - 89 - 5

verely lowering the survival rate of the pest. This would be especially true when the toxin was also repellent to the pest (Gould 1988b); but, again, research in this area is extremely limited.

Use of an inducible promoter that caused production of a toxin in response to initial pest feeding (e.g., Green and Ryan 1972, Carroll and Hoffman 1980) might not slow pest adaptation if any pest feeding induced a lethal level of toxin. However, some inducible promoters might be found that only respond to major levels of damage (Benfey and Chua 1989) and would therefore not select pests for adaptation when their densities were low.

An ideal inducible promoter might be one that would respond to an easily administered environmental signal, perhaps a very specific hormone that was inexpensive to apply or a specific wave length of light. Pesticidal plants whose coding sequences were activated by such promoters would fit into a scouting program where a farmer would use the inducing signal only when pest levels warranted control.

Policy Recommendations

Within the framework of a laissez-faire policy for private development of pesticidal plants, I doubt that any company taking the alternative approaches outlined above would be successful. What farmer in today's economic climate would choose the risk and/or extra cost of using these approaches when he or she could just as easily buy seed that had constituitive expression in all tissues all the time?

Should we and could we regulate the development and use of these pesticidal plants? Even if we decided that regulation was socially justified, enforcement could be problematic. For example, in crops where hybrid seed is not used, it might be difficult to implement the use of seed mixtures. If mixtures were sold, farmers would have a strong incentive to go out into their fields and save seed from plants that had no pest damage (i.e., from the plants that produced the toxin). If they planted these seeds instead of the mixtures available from seed companies, they would get better pest control. Enforcement of regulations would have to be at the individual farm level.

Other than regulation, the only approach that I can see in the near future that could avoid the misuse of overly toxic crops involves the 1990 farm bill. The 1985 farm bill contained an important section dealing with environmental issues. Farmers were given incentives not to plant crops on marginal land where erosion or other negative environmental impacts were likely. Certainly there were pros and cons in the adoption of some aspects of that farm bill. As Congress gears up to develop the 1990 farm bill, it is useful to consider potential improvements on the 1985 bill.

One of the obvious issues facing Congress as it puts this bill together is water quality. Ground water contamination by pesticides is becoming an area of greater concern. Given that pesticidal plants will lessen the negative impact of pesticides on water quality, actions that will increase the useful life of these plants should be supported by farm bill legislation. The research section of the farm bill could call for the USDA to fund public research leading

to testing of cultivars and deployment strategies expected to reduce pest adaptation.

Although some general recommendations could currently be made regarding desirable approaches for using genetically engineered plants, we lack a strong data base to help us determine which of the strategies described above (or other strategies) would be best for a given crop in a specific region. More laboratory experiments and small scale field tests could be of some help, but large scale field tests involving cooperation of a large number of farmers would be the most rigorous approach for gathering data. Acreage available on experiment stations is too limited for such tests.

It is difficult for researchers to convince farmers to use new, untested approaches for producing a crop. However, the excess allotment program for experimental tobacco demonstrates that incentives can be worked into a system that promotes just this type of cooperation. In each of the years 1987, 1988, and 1989, over 100 North Carolina tobacco farmers participated in this program. They helped researchers and received benefits.

A prime "model" pest for a specific program dealing with pesticidal plants would be either the Colorado potato beetle or the diamondback moth. Both of these species have adapted rapidly to synthetic pesticides and are sessile enough to be monitored easily. USDA and university researchers from Maine to Hawaii have been working with these two widespread pests. Potato, the primary host of the Colorado potato beetle, has already been engineered to produce the B.t. toxin, but high yielding varieties with this trait are still years from the market. If government, farmers, industry, and public-supported agricultural researchers worked together, it would be possible to combine the incentives, products, and expertise needed to do large scale field tests of engineered potato varieties before they reach the open market. Knowledge gained from such tests could lead to wiser use of such pesticidal potatoes when high yielding varieties were available. These early tests would require incentives to farmers who participated in the tests in 5–10 carefully selected counties. The farm bill could contain provisions for this. Perhaps potatoes could be allowed on set-aside acres that these farmers had previously used to grow corn or another program crop. Once deployment strategies were worked out on this county level, recommendations, and, if needed, smaller land set-aside incentives could be developed to promote the commercial use of the recommended program.

Based on knowledge gained from county level experiments in the next 5 years, *future farm bills* could be written in a fashion that would give farmers commercial scale incentives to plant mixtures of seed, cultivars with low levels of toxins, or cultivars with targeted toxin expression. Based on provisions in the 1985 farm bill, farmers with a history of growing certain crops like wheat and corn are paid for not growing these crops on a certain percentage of their land. Is it possible that a farmer who uses a seed mixture and thus risks some pest loss could be treated as if he or she had set aside 10–20 percent of the acreage planted? A farmer who planted 100 acres to a cultivar with ecologically beneficial traits would then be reimbursed for 10–20 acres. Alternatively, farmers could be reimbursed based on the yield obtained with cultivars

with approved characteristics as compared to historical yields from that land.

Integrating such approaches into the farm bill will not be simple, but it is time to start structuring the farm bill in a way that will allow such approaches.

The body of this brief has focused narrowly on ways and means to integrate biotechnology into insect pest management. The same approach could be used when considering engineered traits that alter soil nutrient use, control of pathogens, or allow development of entirely new crops. We may not currently be at a stage where new crops can be developed, but if we change a crop's ability to tolerate drought or cold, it could be introduced into States where it had never been grown before. Our past experience with such introductions indicates that there is potential for unanticipated agricultural and environmental consequences. Methodical farm level testing before commercial introduction could help us predict these effects and avoid negative impacts.

American farmers have always been viewed as innovative and adaptable. The approach outlined clearly and importantly involves cooperation and innovation by farmers. Fostering such innovation, whether with biotechnology or other approaches such as IPM or new cropping systems, is likely to help American agriculture and the American society in the long run. The costs of such programs are not likely to be much greater than current set-aside programs.

In terms of research, we certainly need to support innovative, basic research that could not be done by industry, but we also need to support innovative applied research that industry cannot do.

References Cited

Benfey, P.N. and N.-H. Chua. 1989. Regulated genes in transgenic plants. Science 244: 174–181.

Carroll, C.R. and C.A. Hoffman. 1980. Chemical feeding deterrent mobilized in response to insect herbivory and counter adaptation by *Epilachna tredecimnotata*. Science 209: 414–416.

Gould, F. 1988a. Evolutionary biology and genetically engineered crops. BioScience 38: 26–33.

Gould, F. 1988b. Genetic engineering, integrated pest management and the evolution of pests. Tree 3/Bitech 6: S15–19. (Trends in Ecology & Evolution/Trends in Biotechnology).

Green, T.R. and C.A. Ryan. 1971. Wond induced proteinase inhibitor in plant leaves: a possible defense mechanism against insects. Science 175: 776–777.

ECOLOGICAL CONSIDERATIONS AND RECOMMENDATIONS

(By the Ecological Society of America)

Biotechnology has made exciting advances in the last few years. Plants, animals, and microorganisms are now being genetically engineered for use in the environment. For example, tomato plants that protect themselves against insect attack by producing their own insecticides are being developed by several companies. These prototype plants have been tested outdoors and may be ready for commercial planting in the near future. Engineered "ice-minus" bacteria, developed for their ability to protect plants against frost damage, were recently field tested in California. Genetically engineered cotton and soybeans will be field tested during the summer of 1989.

These planned introductions raise questions about the benefits and risks of introducing genetically engineered organisms into the environment. "The Planned Introduction of Genetically Engineered Organisms: Ecological Considerations and Recommendations," [1] a report published by the Ecological Society of America, a professional, scientific, non-profit society, examines these ecological issues. Ecologists are biologists who study the interactions of organisms with their environment, the behavior of individual organisms, interactions between organisms, and the functioning of ecosystems. They can contribute to the discussion on biotechnology using the expertise gained from their study of nature at these different levels of organization. For example, ecologists have studied naturally occurring disease and pest resistance in animals and plants similar to the resistances that might be genetically engineered into domesticated animals and crop plants. They have also studied the movement of plants and animals imported from other parts of the world and their effects on the communities they enter. These and other ecological topics are related to the questions that need to be asked to evaluate the benefits and risks of releasing genetically engineered organisms into the environment.

The report supports the timely development of environmentally sound products, such as improved agricultural varieties, fertilizers, pest control agents, and microorganisms for waste treatment, through the use of advanced biotechnology within the context of a scientifically based regulatory policy that encourages innovation without compromising sound environmental management. With careful design of genetically engineered organisms and proper planning and oversight, the introduction of many genetically engi-

[1] Tiedje, J.M., R.K. Colwell, Y.L. Grossman, R.E. Hodson, R.E. Lenski, R.N. Mack, P.J. Regal. 1989. *The Planned Introduction of Genetically Engineered Organisms: Ecological Considerations and Recommendations.* Ecology 70(2):298–315.

neered organisms can be carried out with minimal ecological risk. Economic, social, and ethical concerns also must be weighed along with strictly ecological and evolutionary considerations, but these other issues were not considered in the report.

At the present time, Federal, State and local governments are developing guidelines and regulations for the environmental release of engineered organisms. The Environmental Protection Agency, the U.S. Department of Agriculture, and other agencies regulate the testing and commercial use of genetically engineered organisms. Congressional hearings on the adequacy of existing legislation and the need for new legislation to regulate the release of genetically engineered organisms were held during the 100th Congress. The report prepared for the Ecological Society of America presents a new framework for regulatory oversight that is based on the attributes of the engineered organism and the environment. The suggested framework for regulatory oversight will be helpful in establishing the degree of regulatory oversight according to the probability of adverse effects.

The wide variety of organisms that will be modified, traits that will be engineered, and environments that will receive altered organisms makes ecological risk evaluation complex. The authors of the report conclude that while they cannot now recommend the complete exemption of specific organisms or traits from regulatory oversight at this time, they support the development of methods for matching the level of oversight to the degree of risk posed by the introduction of a specific genetically engineered organism.

A primary conclusion of the report is that genetically engineered organisms should be evaluated and regulated according to their biological properties (phenotypes) rather than the genetic techniques used to produce them. For example, in the case of insecticide-producing tomato plants, the biological properties of the plants, rather than the laboratory techniques used to make them, should be analyzed to determine whether it is safe to plant them in agricultural fields. The engineered plant's ability to kill caterpillars feeding on it, its growth characteristics, and its other properties should be the objects of evaluation and regulation. Because biotechnology offers the opportunity to develop plants, animals, and microorganisms with genuinely new characteristics, the products of these new techniques may require greater regulatory scrutiny than organisms produced by traditional techniques.

Animal breeding, plant hybridization, and other traditional techniques of genetic manipulation, often produce multiple, unknown effects on the genetic make-up of the hybrid organism, with unexpected effects on the its biological properties. In contrast, the precision with which genetic alterations can be made with molecular techniques is often cited as an argument for the safety of genetically engineered organisms. Although the capability to produce precise genetic alterations increases the confidence that unintended changes in the gene have not occurred, precise knowledge of the genetic make-up of an organism does not allow the prediction of all ecologically important attributes of the organism.

Many important scientific issues must be considered in evaluating the potential ecological consequences of the planned introduction of genetically engineered organisms into the environment.

These include survival and reproduction of the introduced organism, interactions with other organisms in the environment, and effects of the introduced organism on ecosystem function. The framework for ecological oversight proposed in the report is summarized in the accompanying tables. Attributes of the engineered trait, the parent organism, and the environment into which the genetically engineered organism will be introduced must be considered.

The size and frequency of the introduction of genetically engineered organism will affect the probability of population establishment. Under most circumstances, small scale field tests will involve the introduction of a limited number of organisms into a limited environment, on one or a few occasions. Thus, the use of small scale field tests, when justified by previous laboratory and/or greenhouse studies, under conditions that minimize dispersal and under appropriate regulatory oversight, is encouraged. Field experimentation and data from population monitoring are also crucial in evaluating the potential for larger scale environmental effects.

Engineered genes may be transferred from the genetically engineered organism to other organisms through a number of processes. If such lateral transfer occurs, an engineered gene may persist in the natural environment even after the genetically engineered organism itself is no longer present. The available scientific evidence indicates that lateral transfer among microorganisms in nature does occur, so that it cannot be ignored. In addition, this transfer is not so common that it can be assumed the genetic transfers carried out by fern biotechnology are comparable to those that occur in nature.

Native species, as well as species newly introduced from distant habitats, may become pests. An organism engineered to prosper in a new habitat type, geographic area, or season is effectively an introduced organism in that it will probably enter into new biotic and abiotic interactions. Therefore, regulatory and risk assessment structures that rely on the distinction between "native" and "nonnative" must be used with caution.

Scaling of Regulatory Oversight

When analyzing a proposal for introducing a genetically engineered organism into the environment, three types of questions need to be explored. They are questions about the new trait that has been engineered into the organism, the characteristics of the "parent" (wild type) organism which received the trait, and the environment into which the organism will be introduced. As an example, consider that genes to produce new proteins are being engineered into potatoes to balance their nutritional characteristics and improve the diet of people who eat potatoes as their primary food. In this case, the engineered trait is the new protein. questions about the new trait to consider include: Does the production of the protein affect the growth and development of the plant? Are the characteristics of the new protein understood? Questions about the characteristics of the "parent" potato include: Is the "parent" potato fully domesticated or can it live on its own without human

help? Can the "parent" potato exchange pollen with weedy relatives? Questions about the environment where the potatoes will be planted include: Do wild relatives live nearby? Will the potatoes be planted in a wide variety of places or only in a very restricted area? The answers to these types of questions will suggest whether this particular genetically engineered organism requires a low or a high degree of regulatory oversight.

These types of questions are summarized in tables accompanying the report (Table 1). The tables present a preliminary attempt at developing a comprehensive overview of attributes that may permit a *priori* scaling of regulatory oversight for the testing and use of genetically engineered organisms in the environment. Ecological risk assessment and regulatory oversight of genetically engineered organisms, for either field testing or commercial use, require consideration of many factors. Some may be quantified, such as numbers of organisms to be released, size of test plots, or susceptibility of organisms to biocides should mitigation be necessary. Many factors are, however, necessarily qualitative or only roughly quantifiable, such as the level of domestication of the parent species, or the infectivity or virulence of the parent organism. Nonetheless, it is essential to develop some practical means of scaling the level of regulatory oversight according to the probability of adverse effects. Such scaling is equally essential as a means of focusing risk assessment on only those features of organisms and environments that require it.

Three features of Table 1 must be stressed. First, the scaling of each attribute is only qualitative or semiquantitative (ordinal). Second, the scales for any two attributes (any two lines in the table) are not necessarily commensurate, either in terms of the probability of adverse consequences or the severity of such an outcome, if realized. Third, the table is multidimensional. Overall estimates of risk for a particular genetically engineered organism in a particular environmental context require, in effect, a simultaneous mapping of the attributes of the case on all the individual scales of the table. The estimate of risk based on one scale may be greatly modified by the score on other scales. For example, if the parent organism is a pathogen ("habit" scale in Part B), then a broadened host range ("host range" scale in Part C) will yield a higher estimate of risk than would a non-pathogenic organism with a comparably broadened host range.

Scores on the different scales of the table cannot be combined. Not only are they incommensurate, but scores on different scales are also neither strictly multiplicative (as fully independent probabilities would be), nor strictly additive. Experience with real cases will ultimately provide information on actual levels of risk for many regions of this multidimensional space.

At this time, any case that falls at the right-hand end of one or more scales in Table 1 should receive appropriate regulatory scrutiny in regard to the attribute(s) in question. Ecological safety, as well as public confidence in a fledgling industry, will be fostered by this approach.

Comments on Current Regulatory Policy

The current regulatory framework uses biological characteristics and existing institutions (e.g., Federal agencies, universities, industrial laboratories) to structure the oversight process. Certain aspects of the regulatory framework warrant comment from an ecological perspective.

Case-by-case review. The current regulatory practice for review of proposed environmental introductions uses a case by case analysis of the organism, environment, and experimental protocol. Case by case review is currently the most scientifically sound regulatory approach because of the diversity of products that can be developed and the complexity of predicting their ecological fate. Workable guidelines that include categories of organisms requiring minimal screening and review, as well as those requiring more intensive review, will be developed after experience is gained from field experiments and from research that is stimulated by ecological risk assessment. These guidelines should be based upon the types of attributes of transgenic organisms and environments described in Table 1. The regulatory system should remain flexible so that it can easily accommodate new information.

Product versus process. Current regulatory policy is focused on organisms produced by recombinant DNA technology. For the reasons discussed in the Scientific Issues section, the phenotype of the transgenic organism, not the technique used to produce it, is the appropriate focus of ecological risk assessment and regulatory oversight. Nonetheless, because many novel combinations of properties can be achieved only by molecular and cellular techniques, products of these techniques may often be subjected to greater scrutiny than the products of traditional techniques.

Coding versus non-coding regions. Under current governmental policy, insertions of well characterized, non-coding regulatory regions of the genome (DNA), regardless of their source, are assumed to pose no higher risk than does the unaltered recipient organism. Regulatory regions of the genome, such as promoters and repressors, however, serve to control the level and timing of the production of gene products, in some cases turning production on or off entirely. Thus, ecologically important aspects of the phenotype may be altered when a non-coding regulatory region is inserted. Thus, non-coding regulatory regions should not be exempted from ecological risk analysis and regulatory oversight.

Categorization by lists of taxa and vectors. Taxonomic lists of organisms and vector type are used by some regulatory agencies in determining the level of review required for a proposed introduction. Such categorization of safety by taxonomic listing is sound in some cases, but not in others. The biology of most crop plants is well understood, whereas the ecological characteristics of many bacteria are not, and the ecological characterization of vectors is nonexistent. A belief that any given gene exchange demonstrable in the laboratory is commonplace in nature is a hypothesis that has yet to be confirmed or rejected, and thus should not be the cornerstone of regulatory policy. Lists of taxa and vectors categorized for environmental safety are only appropriate when substantiated

by an ecological data base for that organism, including data on the attributes listed in Table 1.

Commercial versus non-commercial research. The current regulatory framework partitions regulatory oversight according to funding source. One particularly troublesome aspect of this practice is the separation of commercial (privately funded) research from noncommercial research. From a scientific point of view, the risk from the introduction of a particular transgenic organism is the same whether the introduction is made by a scientist from the private sector or a university professor. Scientific concerns should guide oversight of planned introductions into the environment regardless of funding source. Ecological risk assessment should be sound and equal for both commercial and noncommercial research.

Development of Regulatory Oversight

The first deliberate environmental introductions of genetically engineered organisms have been made using organisms altered in ways that present minimal ecological risk. Maintaining this approach for now allows time for the development of appropriate ecological risk assessment methods for future use, possibly including a set of categories and risk factors such as is outlined in Table 1. Because the first introductions are especially likely to be innocuous, there may be a tendency to overgeneralize from these examples. The absence of problems at an early stage indicates that the screening mechanisms are working correctly but should not be interpreted to mean that the introduction of all genetically engineered organism is inherently safe. The appropriate use of early experience from field introductions is to establish principles and refine the regulatory structure in order to balance true risk with the extent of review.

Ecological effects and the geographic ranges of organisms transcend political boundaries, therefore, it is essential to promote and achieve international coordination of risk assessment and regulation of biotechnology. Special consideration must be given to the protection of rare genetic resources, such as the wild ancestors of domesticated species and threatened gene pools of other wild species. Local, State, national, and international cooperation is needed in the regulation, risk assessment and risk management of ecological effects of the introduction of transgenic organisms.

Evaluating the benefits and risks of biotechnology products requires expertise in many scientific disciplines including molecular biology, genetics, cell biology, evolutionary biology, physiology, population and community ecology, and ecosystem science. For society to realize the full benefits of biotechnology, interdisciplinary research and graduate training programs are needed to expand the expertise of the scientific community at large.

TABLE 1. Attributes of organisms and environments for possible consideration in risk evaluation.*

A. Attributes of genetic alteration

	Level of possible scientific consideration		
	Less		More
Characterization	Fully characterized		Poorly characterized or unknown
Genetic stability of alteration	High (e.g., chromosomal)		Low (e.g., extra-chromosomal)
Nature of alteration	Gene deletions (unless host range altered)	Single gene added	Multiple genes added
Function	None (no expression or regulation)	Regulation of existing gene product	Synthesis of gene product new to parent organism
Source of insertion	Same species	Closely related species	Unrelated species
Vector	None	Non-self-transmissible	Self-transmissible
Source of vector	Same species, non-pathogen	Closely related species, non-pathogen	Unrelated species or pathogen
Vector DNA RNA in altered genome	Absent	Present, but non-functional	Functional

B. Attributes of parent (wild type) organism

	Level of possible scientific consideration		
	Less		More
Level of domestication	Unable to reproduce without human aid	Semi-domesticated, wild or feral populations known	Self-propagating, wild
Ease of subsequent control	Control agents known		No known control agents
Origin		Indigenous	Exotic
Habit	Free-living		Pathogenic, parasitic, or symbiotic
Pest status	Relatives not pests	Relatives pests	Pest itself
Survival under adverse conditions	Short term		Long term (e.g., spores, cysts, seeds, dormancy)

TABLE 1 Continued.

Geographic range, range of habitats	Narrow		Broad or unknown
Prevalence of gene exchange in natural populations	None		Frequent

C. Phenotypic attributes of engineered organism in comparison with parent organism

	Level of possible scientific consideration		
	Less		More
Fitness	Reduced irreversibly	Reduced reversibly	Increased
Infectivity, virulence, pathogenicity, or toxicity	Reduced irreversibly	Reduced reversibly	Increased
Host range	Unchanged		Shifted or broadened
Substrate, resource	Unchanged	Altered	Expanded
Environmental limits to growth or reproduction (habitat, microhabitat)	Narrowed but not shifted		Broadened or shifted
Resistance to disease, parasitism, herbivory, or predation	Decreased	Unchanged	Increased
Susceptibility to control by antibiotics or biocides, by absence of substrate, or by mechanical means	Increased	Unchanged	Decreased
Expression of trait	Independent of environmental context		Dependent on environmental context
Similarity to phenotypes previously used safely	Identical	Similar	Dissimilar

D. Attributes of the environment

	Level of possible scientific consideration	
	Less	More
Selection pressure for the engineered trait	Absent	Present

TABLE 1. Continued

Wild, weedy, or feral relatives within dispersal capability of organism or its genes	Absent		Present
Vectors or agents of dissemination or dispersal (mites, insects, rodents, birds, humans, machines, wind, water, etc.)	Absent or controllable		Present, uncontrollable
Direct involvement in basic ecosystem processes (e.g., nutrient cycling)	Not involved	Marginally involved	Key species
Alternative hosts (partners), if organism is involved in symbiosis (mutualism)	Absent		Present
Range of environments for testing or use; potential geographical range	Very restricted		Broad, widespread
Simulation of test conditions	Not difficult to simulate realistically		Very difficult to simulate realistically
Public access to test site	Tightly controlled	Limited	Uncontrolled
Effectiveness of monitoring and mitigation plans	Proven effective		Untested or unlikely to be effective

* Position on scale is only qualitative or semi-quantitative. The importance of position on one scale may be contingent on another scale. The importance of particular scales will vary with different cases.

BIOTECHNOLOGY: REGULATION

USDA'S OVERSIGHT OF BIOTECHNOLOGY

(By Rebecca J. Goldburg, Ph.D. Environmental Defense Fund, New York, NY)

INTRODUCTION

Modern genetic engineering gives humans the power to create organisms with traits from disparate evolutionary lineages. Because the ecological consequences of releasing such genetically engineered organisms (GEO's) into the environment are often uncertain, there is good reason to screen releases before they occur. Although careful analysis suggests that many GEO's that scientists will create for agricultural purposes will pose little environmental risk, experience demonstrates that, on occasion, intentional introductions of novel agricultural organisms can have disastrous consequences. Africanized bees, for example are the result of a honeybee breeding program (Page, 1989). Kudzu, not a weed in its native Japan, was imported to the United States as a forage plant and for erosion control (Gleason and Cronquist, 1963). A recent excellent report by the Ecological Society of America (Tiedje et al., 1989) and summarized in this print, provides a detailed rationale for regulation of GEO's.

Federal agencies currently oversee releases of GEO's under the Coordinated Framework for Biotechnology, a policy statement issued by the White House Office of Science and Technology Policy (1986). The Coordinated Framework patches together preexisting statutes administered by a number of agencies to regulate the products of biotechnology. Releases of GEO's are overseen primarily by USDA and EPA under four statutes; Federal funding agencies have authority over research they support. EPA has jurisdiction over most genetically engineered microorganisms. USDA regulates GEO's it considers or animal pharmaceuticals or potential plant pests.

A number of individuals have criticized the Coordinated Framework's regulatory scheme for releases as a poor substitute for new legislation (Goldburg, 1987; Jaffe, 1987; Mellon, 1988). Because the statutes involved were not written to regulate GEO's, they are not always appropriate for this purpose. The Framework also has gaps, overlaps, and inconsistencies that worry environmentalists and confuse nonlawyers—especially academic researchers.

Some problems with the Coordinated Framework can only be solved by enactment of comprehensive legislation covering releases of genetically engineered organisms. There are, however, weaknesses in the Framework that could be improved on an agency-by-agency basis. Parts I and II of this paper focus on how oversight of releases bu USDA's Animal and Plant Health Inspection Service (APHIS) and Agricultural Biotechnology Research Advisory Committee (ABRAC) could be improved. ABRAC is coordinated by the

Office of Agricultural Biotechnology (OAB), part of USDA's Science and Education arm. Part III suggests steps to limit environmentally undesirable but unregulated effects of one class of GEO's: herbicide tolerant plants.

(I) Regulation by APHIS

APHIS regulates GEO's under the Virus, Serum, and Toxin Act (VSTA), the Plant Quarantine Act (PQA) and Federal Plant Pest Act (FPPA). The FPPA is essentially an extension of the PQA; APHIS uses the two statutes together and I shall refer to them as the FPPA.

A. SCOPE OF FPPA

The FPPA was written to prevent the introduction to the United States and interstate movement of plant pests, defined as "any insects, mites, . . . or other invertebrate animals, bacteria, fungi, parasitic plants or any infectious substances, which can directly or indirectly injure plants." Under the Coordinated Framework, APHIS has asserted jurisdiction over organisms, altered with recombinant DNA (RDNA) techniques, that contain genetic material from an organism on APHIS's list of plant pests. For the following four reasons, this scheme is legally and scientifically flawed.

First, nonparasitic plants, including weeds, are conspicuously absent from the FPPA's definition of plant pest. APHIS arguably has thin legal authority to regulate genetically engineered plants. Yet, as of August 1989, 45 of the 48 permits APHIS had issued for releases of GEO's were for plants.

Second, a small piece of the DNA from the bacteria *Agrobacterium tumefaciens* or *A. rhizogenes* is the most common vector used to transfer recombinant DNA molecules into plants. Because *Agrobacterium* is listed as a plant pest, APHIS is able to regulate most plants altered with RDNA techniques. A growing number of other techniques can, however, be used to insert genetic material into plants: electroporation, chemical poration, microprojectiles, microinjection (Weising et al., 1988). Regulating only plants produced with *Agrobacterium* is incomplete oversight.

One of the primary concerns about genetically engineered plants is that they will cross-pollinate with wild relatives and transfer acquired traits to them (Center for Science Information, 1987). This would be of particular concern if a trait such as insect- or herbicide-resistance were transferred to a weed. As it stands, however, APHIS will only screen a plant for potential gene transfer if the plant was produced using *Agrobacterium* or otherwise contains genes from a plant pest.

Third, unlike APHIS's regulations, both EPA draft regulations and USDA ABRAC's draft guidelines for GEO's are "product" rather than "process" based. The trigger for oversight is the genetic novelty of an organism, rather than the process (RDNA in APHIS's case) used to transfer genetic material. This is scientifically sensible, because the concern generated by the release of an organism is a function of what the organism is, rather than how the organism is made. Thus not only are APHIS's regulations at odds

with other Federal approaches, but they are not based on a sound rationale.

APHIS officials sometimes argue that their regulation is product-based, because they only look at organisms with genetic material from plant pests. But, whether a transferred gene originated in a plant pest, or is transferred on a genetic vector from a plant pest, is not a good predictor of whether the product organism will have undesirable effects. Use of *Agrobacterium tumefaciens* as a vector for RDNA, for example, does not automatically imply that the resulting transgenic plant poses special risks (Center for Science Information, 1987). On the other hand, herbicide tolerance can be conferred to plants by a gene from *Salmonella*—which is not a plant pest. Transfer of herbicide tolerance genes from engineered to wild plants is a legitimate concern. Thus APHIS's plant pest criterion appears to be the result of twisting the FPPA to regulate GEO's, rather than the result of scientific analysis.

Fourth, only selected invertebrates and animals with genetic material from plant pests are covered under APHIS's regulations. Unless part of federally funded research, no Federal agency oversees other releases of genetically engineered animals.

Most genetically engineered domestic animals will probably pose little environmental risk. But there is also considerable interest in genetically engineering fish, largely for aquaculture. At least 9 laboratories in the United States, and 13 in other countries, are engaged in research on transgenic fish (Eric Hallerman and Anne Kapuscinski, pers. comm.), making the size of this effort comparable to work on transgenic farm animals. Novel genes have already been transferred into at least 13 fish species. This spring the ABRAC reviewed the first proposal for outdoor testing of genetically engineered fish—carp with a trout growth hormone gene intended to increase fish size.

Outdoor use of genetically engineered fish poses special ecological concerns. It is hard to prevent the occasional escape of fish from outdoor ponds and raceways to watersheds, where they may breed with natural populations. If genetically engineered fish were engineered to have traits that conferred an advantage in the wild (large size, for example, might be advantageous), these traits could spread in wild populations. With new advantageous traits, these fish could then affect populations of other organisms—for example by having a higher reproductive rate or being more voracious predators. These sorts of ecological effects are of particular concern; experience with fish introduced to new geographic areas, so-called exotic species, has shown that natural fish communities are readily disrupted (Moyle, 1986). A recent American Fisheries Society workshop concluded that introductions of genetically engineered fish should be treated with the samecare as introductions of exotic species (Kapuscinski and Philipp, 1988).

In recent years USDA has increased its investment in aquaculture, and now funds 5 regional aquaculture centers and over 400 research projects. At the moment, genetically engineered fish are only screened for outdoor use if they are part of a federally funded research project. As USDA advances fish engineering, however, other non-federally funded institutions will increasingly also participate in product development. A mechanism is sorely needed to

screen all genetically engineered fish (and shellfish) before they are used outdoors.

I have outlined four problems with the scope of the FPPA as it is being applied to GEO's. In order to remedy them Congress should provide APHIS an explicit mandate to regulate non-microbial GEO's used in agriculture (EPA already regulates microorganisms), including those engineered with techniques other than RDNA or that do not contain genes from a plant pest. Because there is interest in genetically engineering animals besides fish and livestock, such as insects for pest control (U.S. Congress, 1988), the new statutory authority should be general enough to encompass all genetically engineered animals. The Fish and Wildlife Service should also be directed to participate in reviews of genetically engineered animals, such as fish, which may harm or alter wild animal populations.

B. APHIS'S AUTHORITY TO PROTECT THE ENVIRONMENT

USDA's mandate is to "protect and enhance agriculture and forestry in the United States." Like all Federal agencies, USDA is subject to the National Environmental Policy Act (NEPA). Under NEPA, agencies must disclose the environmental consequences of their actions, but agencies are not required to give priority to environmental concerns. In short, USDA has no enforceable mandate to protect the environment.

Future proposed releases of GEO's may pose a conflict for APHIS between allowing use of profitable agricultural products and long-term environmental protection. Congress should stipulate that APHIS shall not approve the release of any GEO when there is a reasonable expectation that the release will significantly harm natural communities of organisms or otherwise cause significant environmental degradation.

C. PUBLIC PARTICIPATION IN APHIS REVIEWS

Genetic engineering is new, and releases of GEO's have generated keen public interest. Much to APHIS's credit, over a year ago the service started publishing notices of applications for release permits in the Federal Register. But knowing that an application has been received is of little use if the public does not have access to the information necessary to evaluate the impact of a proposed release.

In theory, any member of the public can obtain a complete application by making a request under the Freedom of Information Act (FOIA). In practice, public access to information is often limited because applicants can—and typically do—declare substantial portions of applications as confidential business information (CBI). If an individual files a FOIA request for a document that may contain CBI, USDA affords the submitter ". . . time in which to object to the disclosure of any specified portion of the information. The submitter must explain fully all grounds upon which disclosure is opposed" (7 CFR 1.8(a) (3)). USDA must then consider the views of the submitter when determining whether to disclose information.

This process can be very time consuming and can deny the public meaningful participation in USDA decisionmaking. In Janu-

ary, 1989, for example, the National Wildlife Federation filed a FOIA request for information concerning a proposed field test of a genetically engineered rabies vaccine. Some of the requested information had been declared CBI by the test's sponsor, the Wistar Institute. APHIS approved Wistar's field test under the Virus, Serum, and Toxin Act in April, 1989. As of June, 1989, the Wildlife Federation had not received an official response to their FOIA request (Jane Rissler, pers. comm.).

Lack of access to information is also problematic for State agriculture agencies. Under the FPPA, APHIS has a laudable policy of consulting with appropriate State officials about permit applications. But APHIS blocks out any CBI before sending applications to State officials. If State officials need this CBI to evaluate whether a permit should be granted, they must wait for a determination from APHIS as to whether the information should be disclosed.

Two steps can be taken to improve public and State access to information. First, APHIS should require that submitters substantiate all confidentiality claims *at the time these claims are made.* Requiring upfront substantiation could greatly speed USDA's processing of FOIA requests. In addition, upfront substantion would give submitters an incentive to allow public disclosure. At present it is easier for submitters to unthinkingly claim large portions of submissions as CBI than to evaluate whether the public reasonably should have access to some of this material. Requiring substantiation would provide submitters an incentive only to claim as CBI information when they have legitimate reason to do so. At the same time, substantiation need not be burdensome to submitters; it need only involve writing a brief explanation of why information should be confidential.

EPA has now drafted rules to do just this for CBI claims pertaining to releases of GEO's. EPA has recognized that frequent confidentiality claims have made crucial information difficult for the public to obtain. USDA should follow EPA's lead.

Second, information necessary to judge the environmental effects of releases of GEO's—including intended use of the product, identification of recipient and donor organisms, information on gene transfer to other organisms, and any relevant ecological studies—should not be allowed to be held confidential. People have a right to voice their opinions regarding decisions that may affect their health, safety, or the integrity of agricultural and natural ecosystems. But the only way the public can effectively participate in government decision-making is if it has access to the relevant information. Congress should mandate that USDA establish regulations to make such information available.

Oversight of Biotechnology by the ABRAC

The Agricultural Biotechnology Research Advisory Committee was formally established by USDA in March 1988. According to its charter, the purpose of the committee is to "serve the Secretary of Agriculture through the Assistant Secretary for Science and Education in an advisory capacity with respect to policies, programs, operations, and activities associated with the conduct of agricultural biotechnology research." Most of its members are academic and

industry scientists involved in biotechnology research. So far, ABRAC meetings have been devoted largely to drafting guidelines for USDA sponsored biotechnology research "outside the laboratory." As of August, 1989, these guidelines had not been proposed.

ABRAC intends to implement these guidelines itself by using Institutional Biosafety Committees (IBC's). All USDA funded institutions will have an IBC, consisting largely of scientists at that institution. Certain classes of proposals for research outside the laboratory with GEO's will be reviewed by ABRAC. Other, presumably less risky classes of proposals, will be reviewed by IBC's. USDA hopes that this system of largely local oversight will expedite decisions regarding research proposals.

USDA's and especially USDA Science and Education's (S&E's) involvement in ensuring the safety of biotechnology research raises an important issue. Should an agency promoting a technology, as USDA—especially S&E—is biotechnology, also be involved in its oversight? As experience with the Atomic Energy Commission painfully demonstrated, such divergent goals can yield ineffective oversight. This conflict of interest may extend to ABRAC and IBC's. Academic biologists with expertise in biotechnology frequently serve as industry consultants and their research is frequently supported with corporate dollars (Doyle, 1985; Kenney, 1986). The North Carolina Biotechnology Center recently found that 79 percent of 565 biotechnology researchers surveyed at North Carolina universities and colleges are interested in collaborating with industry. Academic institutions also stand to make considerable money from biotechnology research. For example, in fiscal year 1988–1989, Stanford University expects to make $4.9 million from its patent on recombinant DNA techniques (Caruso, 1989). In short, ABRAC members, IBC members, and the institutions they work for, may have financial ties to the biotechnology industry, giving them an interest in promoting the industry.

IBC members will also be in the position of publicly allowing or disallowing their colleagues' experiments. Individual IBC members may have a keen interest in the outcome of IBC deliberations—either for personal reasons or because they feel their decisions will affect their professional status. One might argue that these conflicts will prove tolerable because the IBC process is similar to the peer review process for scientific journal articles and funding of research proposals. But there are several distinctions. Peer review tends to be confidential and typically is performed by individuals at outside institutions. Printing a particular journal article or funding a particular research project is generally of far less consequence to the public than releasing GEO's into the environment.

Because the Coordinated Framework depends on Federal funding agencies to oversee research they support, conflicts between promoting and overseeing biotechnology cannot be eliminated without replacing the Framework. One can argue whether or not this oversight by funding agencies should be eliminated. But as long as they are to have an oversight role, measures should be taken to minimize actual and perceived conflict of interest.

To date, USDA has not required conflict of interest statements listing non-Federal employment and financial interests from ABRAC members. Conflict of interest statements should be ob-

tained and *made available to the public.* IBC members should file similar statements with USDA and they should similarly be made available.

Biotechnology research projects at academic institutions are frequently sponsored by industry. No project sponsored all or in part by a commercial institution, in which the commercial institution retains any patent or licensing rights, should be reviewed by an IBC or ABRAC. In such a situation the researcher is a contractor to industry and should be regulated by EPA or APHIS.

Proposals containing CBI should be reviewed by ABRAC, not an IBC. Almost by definition, the existence of CBI indicates that the researcher's institution or sponsor hopes to profit from the research project. In such situations IBC members may be subject to special pressure to do what is in the financial interest of their institution. Moreover, because information used to reach a decision would not be available to the public, the IBC's decisions would not be fully accountable to the public.

Public participation in ABRAC and IBC decisionmaking should be encouraged. The public should be notified of all IBC meetings and these meetings should be open to public. USDA should continue to provide notice of ABRAC meetings and, except for portions in which CBI is discussed, make them open to the public.

Unregulated Indirect Effects of GEO's: Herbicide Tolerant Plants

USDA's regulatory structure screens GEO's for direct risks of outdoor use—whether they are likely to transfer their acquired genes to wild species, have traits likely to make them agricultural pests, and so on. This risk-based regulation does not, however, screen GEO's for their indirect environmental effects—such as whether they will greater encourage use of agricultural chemicals.

Herbicide tolerant plants (HTP's) are a rapidly growing class of GEO's whose use may encourage environmental degradation, *but are unlikely to be regulated for these indirect effects.* In this section I will:

(a) Provide backround on their development;
(b) Explain the environmental implications of this; and
(c) Recommend congressional action.

A. DEVELOPMENT OF HERBICIDE TOLERANT

HTP's resist herbicide applications which kill weeds. Certain plants naturally tolerate certain herbicides. Grasses, for example, naturally tolerate particular herbicides that kill broad-leaved plants. Other HTP's have been created by traditional selective breeding, using hybridization to move genes from HT wild plants to closely related crop plants. But, only with the advent of modern biotechnology have we gained the ability to make large classes of crops resistant to large numbers of herbicides. This is because once a gene that confers tolerance is discovered, it can potentially be moved into any organism.

HTP are likely to be one of the first commercial applications of agricultural biotechnology. According to a publications survey by The Rural Advancement Fund International, at least 30 institu-

tions have launched 80 research programs on HTP's. A subset of these plants, resistant to at least six types of herbicides, have been or are about to be field-tested. Biotechnology-produced HTP should be on the market in the early to mid-1990's (Genetic Technology News, 1989).

There is a tremendous financial incentive for companies to develop plants that tolerate herbicides that they manufacture, especially if the herbicides are still on patent. The herbicide market is large: roughly 650 million pounds of herbicide active ingredients are used every year in the United States, 60 percent of the pesticides used in this country are herbicides (U.S. Environmental Protection Agency, 1987). This market-incentive is compounded by the fact that chemical companies now own a large fraction of the seed companies in this country (Doyle, 1985). Combined marketing of herbicides and seeds could offer considerable profit.

The main risk of using HTP's, as regulated by USDA, is that they will cross-pollinate with wild relatives, and transfer tolerance genes to weeds. Because most major U.S. crops originated abroad, most have few if any wild relatives with which they can hybridize. Gene transfer is more likely to be a significant problem in the Third World, where most of our crops originated. Although gene transfer is a legitimate concern, it's not my major concern about HTP's.

B. ENVIRONMENTAL IMPLICATIONS

On average, less than 1 percent of herbicides reach target weeds (Pimentel and Levitan, 1986); the rest simply contaminates soil, water, crops, and so on. What are the effects of this excess herbicide? Because herbicides are meant to kill plants, which differ physiologically from animals, they tend not to be acutely toxic to mammals. A number of herbicides have, however, been implicated as chronic toxins. The National Academy of Sciences estimates that 31 percent of the cancer risk of pesticides on fresh foods is due to herbicides (National Academy of Sciences, 1987). Perhaps the most serious environmental problem caused by herbicide use is ground water contamination. Of the 54 pesticides with confirmed detections in ground water, almost half are herbicides (U.S. Environmental Protection Agency, 1988). This contamination is particularly serious because over half the U.S. population depends on ground water for drinking water, and, once ground water is contaminated it cannot be cleaned up.

HTP's will undoubtedly alter patterns of herbicide use. Proponents of HTP's argue that the plants will be environmentally beneficial; they will allow farmers to substitute newer more benign chemicals for older more dangerous ones. Crops tolerant to the relatively new herbicides, bromoxynil glyphosate, and the sulfonylureas, are in the field test stage. If farmers could purchase tolerant crops, they could then use these chemicals in place of others. But, these herbicides may turn out not to be safe at all. In May 1989, bromoxynil's manufacturer withdrew some formulations from the market and EPA restricted use of others, after new data demonstrated that this herbicide is absorbed dermally and causes birth defects in rats. And, even if other newer herbicides are "safer"

than older ones, they may still have significant undesirable effects. A surfactant used in glyphosate formulations is acutely toxic to some fish and aquatic invertebrates, and this herbicide persists in runoff water (Monroe, 1988). Because minute amounts of sulfonylureas are lethal to plants, pesticide drift can be devastating to neighboring fields. Do we really want to promote use of these chemicals instead of developing products and practices that lessen or provide alternatives to herbicide use?

Furthermore, work on HTP's is not limited to allegedly safe herbicides. According to the Rural Advancement Fund survey, crops have been or are being developed to resist herbicides—including metribuzin, trifluralin, and atrazine—that are suspected chronic toxins and leach into ground water.

Proponents argue that that HTP's will lower herbicide use. But even small quantities of some herbicides, such as atrazine, can leave soil residues that damage subsequent crops. HTP's would allow farmer's to increase herbicide use without worrying about residues. HTP's might also discourage the switch by some Corn Belt farmers from broadcast application to banding (applying herbicide only to crop rows), since by applying more herbicides they might begin to approach 100 percent weed control without mechanical cultivation.

Proponents argue that HTP's would give farmers more options for weed control. But if HTP's cause certain herbicides to become very widely applied, weeds resistant to these herbicides are likely to evolve. Farmers would not then be able to use these herbicides when legitimately needed, such as in Integrated Pest Management (IPM) programs.

Finally, HTP's could be developed for any situation in which herbicides are used. The U.S. Forest Service is sponsoring research to develop HT trees. At present, only a small fraction of forest is treated with herbicide, usually before or shortly after tree seedlings are planted. Arguing that the other weed control measures now used are expensive, the Forest Service researchers would like to promote increased herbicide spraying by engineering resistant trees (Nelson and Haissag, 1986). HT trees might make economic sense, but associated herbicide use could injure flora and fauna. In other words, use of HT trees would be a strong expression of timber primacy—the idea that forests are managed for timber production, not conservation.

In summary, HTP's are likely to entrench agriculture's reliance on chemicals. There may be some immediate environmental benefits from use of HTP's, due to substitution of newer for older herbicides. But in many situations HTP's will probably promote degradation of agricultural and natural ecosystems.

C. OPTIONS FOR CONGRESS

HTP's are currently unlikely to be regulated for their indirect effects on chemical use. (Under NEPA, APHIS could theoretically block those regulated under the FPPA.) Although perhaps in legislation other than the farm bill, EPA should be given a mandate to specially consider HTP's under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). EPA already registers herbicides for

use on particular plants under this statute. EPA should be given clear authority to register herbicides for use with HTP's separately from other crops. HTP's that promoted increased herbicide use or other environmental degradation should not be used.

USDA should indirectly "regulate" HTP's by not promoting their development. The 1990 farm bill should stipulate that USDA funds cannot be used for mission-oriented research to develop HTP's. USDA already sponsors a number of projects involving HTP's (although not all involve modern biotechnology). The U.S. Forest Service funds at least one project, the 1988 Cooperative States Research Service competitive grants program two projects, and the Agricultural Research Service six projects. Federal formula funds and industry dollars probably sponsor considerable additional research on HTP's at land grant institutions.

Instead of supporting the development of HTP's, Government funds should support the development and implementation of weed control measures that could lessen dependence on herbicides. Numerous measures deserve further research: crop rotation, cover crops, intercropping, breeding crops for allelopathy and early emergence, biological control, IPM strategies, and mechanical cultivation. Government research funds are, unfortunately, scarce. This money should be invested in developing techniques that over the long haul will make agriculture environmentally sound.

Conclusion

Our society has learned that virtually all technologies—from petrochemicals to food preservatives to nuclear power—are double-edged swords. Although they held tremendous promise and still provide benefits, they have also had unforeseen consequences for human health and the environment. This experience implies that it would be wise to assess the environmental implications of the products of new technologies, such as modern biotechnology. As I have outlined, some agricultural biotechnology products may pose environmental risks; others may perpetuate our dependence on hazardous chemicals. Congress should take the necessary steps to ensure that USDA plays an environmentally responsible role in the development ofbiotechnology.

References Cited

Caruso, D. 1989. Will they put profits before ethics? San Francisco Examiner, Feb. 19, p. D-3.

Doyle, J. 1985. Altered Harvest. Viking-Penguin, New York.

Center for Science Information, 1987. Regulatory Considerations: Genetically-Engineered Plants. Summary of a workshop at the Boyce Thompson Institute for Plant Research at Cornell University.

Genetic Technology News. 1989. Herbicide-resistant plants: big market, and better weed control. 9:8, 11.

Gleason, H.A. and A. Cronquist. 1963. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. D. Van Nostrand, New York.

Goldburg, R.J. November 5, 1987. Testimony on Federal regulation of biotechnology before the Subcommittee on Hazardous

Wastes and Toxic Substances of the Senate Environment and Public Works Committee.

Jaffee, G.A. 1987. Inadequacies in the Federal regulation of biotechnology. Harvard Environmental Law Review 11:491–550.

Kapuscinski, A.R. and D.P. Philipp. 1988. Fisheries genetics: issues and priorities for research and policy development. Fisheries 13:4–10.

Kenney, M. 1986. Biotechnology: the University-Industrial Complex. Yale University Press, New Haven.

Mellon, M. 1988. Biotechnology and the Environment. National Wildlife Federation, Washington, DC.

Monroe, D.H. 1988. Ecological and public health implications associated with glyphosate herbicides. Environmental Consultants Northwest, Stanwood, WA.

Moyle, P.B. 1986. Fish introductions into North America: patterns and ecological impact, pp. 27–43 in H.A. Mooney, J.A. Drake (eds.) Ecology of Biological Invasions of North America and Hawaii, Springer-Verlag, New York.

National Academy of Sciences, National Research Council. 1987. *Regulating Pesticides in Food: The Delaney Paradox.* National Academy Press.

Nelson, L.R. and B.E. Haissag. 1986. Herbicide stress: use of biotechnology to confer herbicide resistance to selected woody plants. In: *Stress Physiology and Forest Productivity.* M. Nijhoff and M.A. Hingham, eds. Kluwer Academic Publishing.

Office of Science and Technology Policy. 1986. Coordinated Framework for Regulation of Biotechnology. Federal Register, 51:23302–23350.

Page, R.E. 1989. Neotropical African bees. Nature 339:181–182.

Pimentel, D. and L. Levitan. 1986. Pesticides: amounts applied and amounts reaching pests. Bioscience 36:86–91 Regal, P. 1986. Models of genetically engineered organisms and their ecological impact, pp. 111–132 in H.A. Mooney, J.A. Drake (eds.) Ecology of Biological Invasions of North America and Hawaii, Springer-Verlag, New York.

Tiedje, J.M., R.K. Colwell, Y.L. Grossman, R.E. Hodson, R.E. Lenski, R.N. Mack, P.J. Regal. 1989. The planned introduction of genetically engineered organisms: ecological considerations and recommendations. Ecology 70:298–315.

United States Congress, Office of Technology Assessment. 1988. New Developments in Biotechnology—Field-Testing Engineered Organisms: Genetic and Ecological Issues, OTA-BA-350, Washington, D.C.

U.S. Environmental Protection Agency, Office of Pesticide Programs, 1987. Pesticide industry sales and estimates: 1986 market estimates.

U.S. Environmental Protection Agency, Office of Pesticide Programs, 1988. Pesticides in ground water data base: 1988 interim report.

Weising, K., J. Schell, and G. Kahl. 1988. Foreign genes in plants: transfer, structure, expression, and applications. Annu. Rev. Genet. 22:421–477.

AGRICULTURAL BIOTECHNOLOGY OVERSIGHT: CAPABILITY OR CALAMITY?

(By Edward L. Korwek, Ph.D., J.D., Law Offices of Hogan & Hartson, Washington, D.C.)

The title of this paper may be unnecessarily thought-provoking. Measuring the success of USDA's biotechnology efforts to date and assessing the need for new legislation depend upon one's perspective of the role of the Federal Government and, more particularly, of USDA, in striking the proper balance between regulation and promotion or encouragement of research/technological innovation. Because of USDA's dual mission to both regulate and fund agricultural research or the products thereof, or both, perhaps no single Federal department is viewed more often as in a position to strike a proper balance than USDA. Opponents of USDA's involvement in the biotechnology area thus argue that USDA promotes technologies it is supposed to regulate or regulates the technologies it is supposed to promote, depending on the critics' research or regulatory orientation.

USDA's organization that is particularly relevant to biotechnology includes the two main divisions of Marketing and Inspection Services (M&I), which is basically responsible for USDA regulatory functions; and Science and Education (S&E), which is primarily responsible for agricultural research and extension funding. Passage of title XIV of the Food Security Act, called the National Agricultural Research, Extension and Teaching Policy Act Amendments of 1985, arguably now further complicates this combination of funding and regulatory roles of USDA, particularly S&E's traditional orientation toward non-regulatory activities.

Section 1404, amending section 1405(12) of the National Agricultural Research, Extension and Teaching Policy Act of 1977, 7 U.S.C. 3121(12), provides that USDA shall "establish appropriate controls with respect to the development and use of the application of biotechnology to agriculture." This authority has been used so far by S&E to develop draft "guidelines" for research outside the laboratory involving genetically manipulated organisms (*i.e.,* research involving environmental releases), thus resulting in what some consider to be the development of a scheme of "regulation" by S&E, at least for certain types of biotechnology research activities conducted by institutions or persons receiving USDA funds.

More importantly, since the quoted language of section 1405(12) is quite broad, this provision could perhaps be used to provide S&E with "regulatory" authority over other biotechnology activities, including product development and commercialization. The expansive powers granted by section 1405(12), when viewed in conjunction with the current scheme of regulation by M&I and other Federal departments and agencies, make it quite clear that adequate statu-

tory authority is already available to oversee probably all types of agricultural biotechnology activities. Nonetheless, problems and areas do exist, as discussed below, that may warrant the passage of new legislation.

Current Oversight System

Table I provides a summary of Federal agencies involved in oversight of particular agricultural biotechnology applications. Under existing laws, research and commercial applications of biotechnology may be regulated differently and by different Federal agencies. Regulatory oversight within the current legal framework is based primarily on the authority in various laws to require permits or other types of agency review *before* research is conducted or *before* a product is introduced into the marketplace.

TABLE I.—JURISDICTION OF FDA, USDA, AND EPA OVER AGRICULTURAL BIOTECHNOLOGY

	Agency/Office [1]	Significant law(s) [2]	Prior review of research [3]
Animal applications:			
Drugs	FDA	FD&C Act	Yes.
Biologics	APHIS	VSTA	Yes.
In vitro biologic diagnostics	APHIS	VSTA	Yes.
In vitro diagnostics	FDA	FD&C Act	No.
Food and food ingredients	FDA	FD&C Act	No.
Meat and poultry products	FSIS	FMIA & PPIA	No.
Pathogens	APHIS	Various	Yes.
Plant applications:			
Pesticides	OPP	FIFRA	Yes.
Noxious weeds	APHIS	FNWA	Yes.
Pests/pathogens	APHIS	PQA, FPPA	Yes.
Food and food ingredients	FDA	FD&C Act	No.
Meat and poultry products	FSIS	FMIA & PPIA	No.
In vitro diagnostics	OTS	TSCA	Yes.

[1] Animal and Plant Health Inspection Service (APHIS) and the Food Safety and Inspection Service (FSIS) are part of the United States Department of Agriculture (USDA). The Food and Drug Administration (FDA) is a part of the Department of Health and Human Services. The Office of Toxic Substances (OTS) and Office of Pesticide Products (OPP) are part of the Environmental Protection Agency.

[2] FD&C Act: Food, Drug and Cosmetic Act; FIFRA: Federal Insecticide, Fungicide and Rodenticide Act; FMIA: Federal Meat Inspection Act; FNWA: Federal Noxious Weed Act; FPPA: Federal Plant Pest Act; PPIA: Poultry Products Inspection Act; PQA: Plant Quarantine Act; TSCA: Toxic Substances Control Act; VSTA: Virus, Serum, Toxin and Analogous Products Act of 1913.

[3] The regulation of research applications of agricultural biotechnology can take many forms, such as prior review before research work is undertaken or review of the results of an experiment after it is completed. The listing of research work as subject to agency review before it is undertaken does not necessarily mean that all types of research activities are subject to such prior review. Agencies listed as not conducting prior review of research work usually have the authority to do so, but do not currently actively exercise or enforce such authority, often as long as the products of such research activities are properly labeled or handled.

Regulation may or may not be triggered not only by the type of genetic manipulation, such as whether an organism contains genetic information from a different genus, so-called intergeneric microbes, or whether an organism is modified only by non-coding regulatory genetic regions, but also by the intended use of the product, such as whether it is used as a pesticide or a drug. Oversight may also depend on whether a plant or animal pathogen is involved. This regulatory diversity is derived from the variety of Federal (and State) laws that have been enacted for different purposes to protect human and animal health and the environment.

Commonly raised problem areas with the application of current laws to biotechnology activities that have been mentioned as possibly in need of legislative solutions include the following:

• *Overlap.*—Some laws prevent duplicative review by Federal agencies while others do not. One example of possible overlap is in the area of release into the environment of a microorganism containing genetic information from a different genus and subject to the Toxic Substances Control Act (TSCA), such as certain uses of microorganisms in bioremediation. This microbe is not only subject to regulation by the Environmental Protection Agency (EPA), but if plant or non-human pathogens are involved in constructing the genetically altered organism it is also likely to be regulated by USDA, specifically by the Animal and Plant Health Inspection Service (APHIS) within M&I.

• *Definitions.*—The practical application of current laws to the products or processes of modern biotechnological methods is plagued by the inability to develop precise definitions for important terms, which often prescribe not only which Federal agency reviews an activity but also the exact nature of the review process. Examples of terms that have posed some definitional difficulties include "biotechnology," "pathogen," "release to the environment," "recombinant DNA," "naturally occurring/new," and "biologic." The importance of a precise definition for the last term, "biologic," can be highlighted in the context of a specific example. As indicated in Table I, USDA regulates animal drugs that are also biologics (e.g., vaccines), whereas the Food and Drug Administration (FDA) regulates all other types of animal drugs. Precisely defining what is an "animal biologic" therefore determines not only which agency, FDA or APHIS, oversees the research and commercial work, but also the specific requirements for obtaining agency approval.

• *Research versus Commercial Activities.*—This distinction is especially important in the TSCA area, because "pure" (noncommercial) R&D activities are exempt from certain types of TSCA oversight altogether, whereas commercial R&D may not be. Various agricultural laws, on the other hand, often make no distinction between research or commercial activities, particularly where pathogenic organisms are involved, thus usually placing all biotechnology and other activities on an equal regulatory footing.

• *Product versus Process Regulation.*—The current consensus is that any biotechnology regulatory system should be product-, not process based. In other words, the hazards, if any, from exposure to a biotechnology- derived "product," including a genetically manipulated organism, are related more to the traits of the "product," than to how it is made. This approach to oversight has raised the specter that regulatory review may be triggered not only for products of relatively newer technologies, such as R-DNA, but also for those that have been developed through classical techniques, such as plant or animal breeding or somaclonal variation.

• *Complexity.*—The diversity of laws utilized for oversight of biotechnology activities creates a variety of "triggers" for regulation, resulting in confusion as to who regulates what products and under what circumstances. For example, an article used for the prevention of diseases in human beings and other animals would likely be regulated as a drug by FDA, whereas the same article, with claims in labeling and advertising indicating that it is intended to be used on any of a wide variety of organisms defined as "pests," could be

regulated as a pesticide by EPA. Research activities involving a new drug or pesticide may or may not be regulated, depending upon the type of research activity and whether FDA or EPA oversight was involved.

Other areas often identified as in need of at least clarification include defining the precise nature of confidential business information and how Federal agencies should handle such information; whether adequate scientific bases exist, especially in the area of deliberate releases, for the Federal agencies to differentiate low risk from high risk experimentation; and whether existing data requirements to obtain agency clearances are appropriate. The debate in these areas, which sometimes has been heated, will likely continue, particularly with respect to environmental releases of genetically manipulated organisms.

Perspective

Most, if not all of the regulatory problems raised above, and others not specifically discussed here, are difficult to resolve, particularly through legislative initiatives, for a variety of reasons. For example, the development of risk assessment techniques often depends upon advancements in science, which may not exist; the establishment of clear triggers for oversight and of definitions that make scientific as well as legal sense is usually difficult, if not impossible; and avoidance of regulatory overlap and subsequent "turf battles" is nearly impossible when Federal organizations have different statutory mandates. This is true whether such organizations are located within one Federal department, such as USDA, or located among several departments or agencies, such as EPA, FDA, and USDA.

Finally, an important point often overlooked in discussions about the adequacy or extent of biotechnology agricultural initiatives is that the same types of questions or issues usually exist with respect to other products made in conventional ways or with respect to the application of current laws to other technologies. In other words, the development of modern biotechnological methods often raises many old issues or problems in a new context. Few, if any, of the questions or problems associated with the initiatives taken under the current laws are unique to biotechnology. From this perspective, the problems that some argue plague the current scheme of biotechnology oversight therefore tend not always to be technology-based. Consequently, suggesting "biotechnology-specific" remedies, legislative or otherwise, is often difficult without also addressing the more fundamental problems associated with oversight under any statute.

Observations and Recommendations

The foregoing discussion suggests the following:

• No unified theory for oversight of research or commercial applications of modern biotechnological methods has emerged from the regulatory debate, and none can be easily embodied in one statute, any more than one theory of oversight could successfully be developed for any other collection of technologies or industries. The diverse research and commercial applications of modern biotechno-

logical methods suggests, instead, the continued use of administrative approaches under the current legal framework to address such problems as complexity, overlap, and coordination of agency initiatives. A quick legislative fix simply does not exist for many of the problems.

• Nevertheless, some areas may be more amenable to legislative solutions than others; for example, either FDA or USDA regulation of all animal drugs may be desirable. Increased or continued high levels of funding of agricultural biotechnology research and extension is important, not only to keep USDA research and regulatory initiatives in the forefront of biotechnology developments, but also to keep U.S. agriculture competitive in world markets. Indeed, appropriate legislative initiatives in the research area may also increase USDA's familiarity with possible product applications and help USDA develop new or refined approaches to risk assessment. This increased familiarity and the development or refinement of risk assessment methodologies may then reduce product review times or the extent of research oversight, thus helping also to ensure U.S. competitiveness in the agricultural biotechnology area.

• Federal agencies or departments, such as USDA, which have the dual statutory mission to fund and perform research, or both, as well as to regulate research and product applications of new technologies, are placed in a difficult, potential conflict of interest situation. No legislative initiative can now easily eliminate this diversity of purpose within the different divisions of USDA. Nonetheless, with the passage of section 1405(12) seemingly empowering S&E with broad regulatory functions, regulatory authority seems now to exist not only in different divisions within USDA, but also within the same division. Research and regulatory activities should remain distinctly separated within USDA to avoid conflicts problems, a goal that can be encouraged both through administrative and legislative approaches.

• Many research applications of agricultural biotechnology are currently regulated, or at least capable of being regulated, by APHIS (within M&I) or other regulatory agencies under existing laws. New legislation might nonetheless clarify which research applications of agricultural biotechnology are indeed worthy of continued or new oversight, since many current laws administered by USDA, particularly in the plant and animal pathogen area, are so broadly worded as to be impractical to implement or devoid of specific Congressional guidance and, hence, subject to legal challenge. Narrowing the areas of research oversight could also be accomplished administratively by focused regulatory initiatives. Whether any administrative or legislative activity is warranted at all in this area depends upon the desirability of maintaining or granting new broad grants of authority to oversee agricultural research applications of any technology, including modern biotechnological methods.

Any legislative initiatives should not lose sight of the fact that our agricultural system is preeminent because of the decades of U.S. investment in innovation and that innovation, through USDA initiatives; must continue if we are to reap all the benefits of the modern revolution in biology

22-829 - 89 - 6

BIOTECHNOLOGY: AT THE FARMGATE

BIOTECHNOLOGY AT THE FARMGATE: OPPORTUNITIES FOR FARMERS

(By A. Ann Sorensen, Assistant Director, Natural and Environmental Resources Division, American Farm Bureau Federation, Park Ridge, Illinois)

Two key factors have been instrumental in catapulting U.S. farmers to their position of prominence in global agriculture: research and technological innovations. Three years ago, the Joint Council on Food and Agricultural Sciences, which helps coordinate and plan research, extension and teaching for U.S. agriculture, concluded that "The challenges facing research and education in the food and agricultural sciences have never been greater." (JCFAS, 1986). They were optimistic about the promise of biotechnology to help agriculture: "Biotechnology directed towards the area of food and fiber can bring significant economic benefits to the United States." They went on to designate a number of areas for concentrated research efforts involving biotechnology. The case for continued Federal and State Government involvement in agricultural research was succinctly stated in the USDA Yearbook of Agriculture, Research for Tomorrow (USDA, 1986). They outlined seven critical needs for farming in the future:

—increasing productivity to assure more output from available resources;
—improving our ability to compete in world markets;
—developing renewable raw materials;
—improving the quality of our products and processes;
—meeting the food needs of developing countries;
—maintaining flexibility to deal with an uncertain future.

Most farmers would agree with these goals. Many would add an eighth goal to the list:

—continue to evaluate and change agricultural production systems to minimize their impacts on the environment. And, hopefully, keep these changes consistent with the other goals of farm policy.

What Farmers Need

Private industry invests approximately $149 million annually in agricultural biotechnology research (ARI, 1985). Currently, 33 dedicated biotechnology companies and 11 large, diversified companies specialize in plant or animal agriculture in this country (OTA, 1988). Research efforts are market driven, focusing on animal health care products, animal growth regulators, disease and insect resistant crops, herbicide resistant crops, and biopesticides (Ratner, 1989). Crops of interest include corn, cotton, oilseeds, rice, and potatoes.

An additional source of private sector funding for research may evolve from commodity check-off programs. For example, the use of check-off funds for biotechnology R&D could be explored. These self-help programs by farmers should not be penalized by diminished funds from the public sector but should instead be encouraged through a proper mix of matched funding from Federal and State sources.

Despite private sector involvement in R&D, industry's need to market a final product for a profit means that several critical areas of research may be ignored. The farm bill, and perhaps check-off funds, could potentially play a key role in filling these gaps.

I. ALTERNATIVES TO REPLACE ENDANGERED PESTICIDES

The Problem: The availability of agricultural chemicals in the future could have a profound impact on production management systems. A short list of potential problems includes ground water contamination, food safety and pesticide residue concerns, adverse effects on endangered species, health and safety of farm workers, resistance problems, increasing production costs and dwindling supplies of resources (Carter, 1989). Many pesticides may not survive the additional testing for safety and environmental impacts required to re-register older pesticides. The National Academy of Sciences warns that 20 percent of our older pesticides may cause tumors (oncogens) (NAS, 1987). EPA estimates that 20 to 40 percent of the pesticide active ingredients for which interim registration standards are being prepared will trigger alarm bells (special review) (GAO, 1986). EPA has also identified 55 of the inert ingredients used in pesticide formulations as being of "immediate concern" (GAO, 1986). Minor crops (anything other than corn, cotton, soybeans and small grains) may lose 25 to 50 percent of the pesticides now registered for use on them (R.H. Kupelian, personal communication). This potentially rapid attrition rate deeply concerns farmers. For pesticides removed from the market, the availability of alternatives and the rate at which they are adopted will be critical.

SUGGESTIONS

1. *Endangered Pesticide list:* EPA should identify significantly risky but beneficial pesticide uses that are left in place solely because of the absence of satisfactory replacements (GAO, 1986; Benbrook, 1986). For such "reluctantly retained uses," EPA could:

—publicly encourage the development of alternatives;
—accelerate the review of any such alternatives proposed for registration;
—after alternatives are registered, reconsider the pesticide in question.

Upon identification of endangered pesticides, the resources of the USDA should be mobilized to provide safer and reasonably effective replacements through biotechnology. Projects involving alternatives could be favored in the funding process. For example, in 1987 the American Farm Bureau Federation identified 35 pesticides with multiple environmental problems (Sorensen, 1989c).

These are pesticides with a limited future and research should be undertaken immediately to find viable alternatives.

2. *Resistance Problems:* Resistance continues to be a major factor in limiting the effective life of many pesticides. The Pesticide Resistance Study encouraged by the 1985 farm bill should be closely examined. Molecular biology, including recombinant DNA technology, can be directed towards isolating and characterizing specific mechanisms of resistance (NRC, 1986).

3. *Research Priorities:* We should concentrate our research efforts on those crops most threatened by the loss of pesticides and in those areas where environmental problems are most intense. At the same time, we must keep in mind how possible changes will relate to the overall farm sector and to competitiveness in international markets.

Special emphasis should be given to research for controlling or resisting fungal pathogens and nematodes. The National Academy of Sciences reports that 90 percent (by weight) of the fungicides currently in use are oncogens or cause tumors (NAS, 1987). With food safety concerns escalating, these fungicides are coming under closer scrutiny and many may be removed from the marketplace or have use restrictions placed on them. Fungicides are critical for many farmers in the Southeast and other areas of the country where the climate encourages attack by molds, rusts, blights, and other fungal diseases. The probable loss of older fungicides is especially troubling because the "easy chemistry" has been used up and newer fungicides are more likely to create resistance problems because of their mode of action. Nematocides present problems because many are injected directly into the soil, increasing their potential to get into the ground water.

II. TECHNOLOGIES TO MINIMIZE GROUND WATER CONTAMINATION

The Problem: Although we do not yet have definitive surveys, it appears that the potential for ground water contamination from pesticides and nitrogen fertilizers (including manures) is widespread (Sorensen, 1989b). Technologies to prevent contamination from happening or to allow for affordable clean-up will be critical to the future of farming in many areas of the country (Nielsen and Lee, 1987).

Suggestions

1. *Develop More Efficient Cultivars:* We should target research to genetically engineer site specific cultivars or crop varieties which require less fertilizer and pesticides. This type of research will be critical in those areas of the country particularly vulnerable to ground water contamination. For example, insecticide requirements are highest in the Southeast and herbicide requirements are highest in the Northeast and Lake States (Reichelderfer and Phipps, 1988). The relative fertilizer requirements are highest for cotton, corn and grain sorghum. The relative pesticide requirements are highest for cotton, corn and rice. If we want to continue growing these program crops in sensitive areas, we will have to develop cultivars which can use inputs more efficiently. The American Farm Bureau Federation is currently collating data to identify

problem sites and crops (Jim Porterfield, personal communication). For example, a map showing where cotton is being grown over ground water potentially vulnerable to pesticide contamination appears in the Appendix.

Long-term objectives for basis research include:

(1) Improvements in plant photosynthetic efficiency. This is particularly critical in further increasing cereal yields to feed expanding populations (Brown, 1988);

(2) Breeding crops more tolerant of salt or drought (NRC, 1987); and

(3) Developing cultivars with an increased ability to fix nitrogen or an improved ability to take up nutrients, thereby reducing the portion that is lost to the environment (NRC, 1984; Benbrook, 1989).

2. *Herbicide Resistance:* Private industry is currently focusing on the development of herbicide resistance cultivars. About three quarters of the corporate R&D in herbicide resistance is targeted toward the newer and environmentally safer herbicides (Benbrook and Moses, 1986). Potentially, these cultivars could reduce our dependency on herbicides which are environmentally damaging and allow farmers to rely on more benign herbicides. In reduced tillage operations (which help reduce soil erosion), herbicides play an important role in eliminating weeds that compete with crops for nutrients and water.

As we begin to test herbicide resistant cultivars, two potential areas of concern should be investigated more thoroughly:

—weeds are now rapidly evolving resistance mutations to the new generation of environmentally safe herbicides (in 1 to 5 years) (Silva, 1989). How will herbicide resistance crops fit into this picture? The current recommendation to avoid resistant weed populations is to rotate crops where possible. The use of crop rotations in farm programs is influenced by current commodity titles and restrictions.

—some researchers feel that uncontrolled hybridization of weeds by cross pollination and mobilization of genetic elements could be a potential problem (Brosten and Simmonds, 1989). The potential for genes to be transmitted under natural conditions from crops to weeds and vice versa should be examined more closely.

3. *Insect Resistance:* In addition to herbicide resistance, corporate attention has also been focused on genetically transferring the *Bacillus thuringiensis* (B.t.) toxin gene into cultivars. B.t. is our most commonly used insect microbial pathogen. It controls many species of insects. There is a possibility that insects might adapt if continually exposed to the B.t. toxin. Like most potential resistance problems, this one could be minimized by encouraging crop rotation, by the mixing of B.t. and non B.t. cultivars within fields, and by targeting B.t. toxin expression to certain sites within the plant. The first two possibilities need to be addressed in other sections of the farm bill. Targeting B.t. expression represents long term basic research that is suitable for Experiment Station research.

III. PRESERVING AND EXPANDING GENETIC DIVERSITY

The Problem: It is essential that we continue to conserve plant genetic resources (Keystone Center, 1988; CSSA/SAS/SSSA, 1989; Witt, 1985). These resources include cultivated varieties or cultivars currently in use, newly developed cultivars, obsolete cultivars, primitive cultivars (landraces), and wild and weedy species that are closely related to important cultivars.

Suggestions

1. *Maintaining Genetic Diversity:* The farm bill should recognize and encourage those farmers who are willing to maintain obsolete or primitive cultivars on their acreage. One possibility would be to allow farmers with CRP acreage to use a small portion of the acreage to grow primitive cultivars under the direction of the U.S. National Plant Germplasm System (NPGS). This would be a nonprofit undertaking devoted solely to the maintenance of genetic diversity. Another possibility is to set aside Federal lands or Public lands for the same purpose.

2. *Evaluating Site-Specific Crop Varieties:* Farmers could also be instrumental in evaluating the adaptation of cultivars to their local growing conditions. For example, they could be awarded additional crop base acreage for allowing their local Extension Service agent to test new cultivars on part of their land (The tobacco allotment program may provide a model to construct a program to encourage farmers to participate in site-specific research).

Critical Roles for Extension Service

The Problem: Although biotechnology can have a major impact on farming in the future, a critical factor will be how farmers respond to these new technologies: whether they can fit them into their current management practices and whether they will become aware of their availability on a timely basis (Sorensen, 1989c). Many observers wonder if these new technologies will truly be "scale neutral" or whether large farms will have an inherent advantage for whatever reason. Farm size, in general, is an emotionally laden issue. In balancing size of farms, we must be careful not to implement restraints that are in conflict with other technologies and the continuing economic forces shaping farm size and structure. In addition, we need to keep in mind that there is a correlation between the type of commodity grown and the acreage necessary to grow it efficiently and economically.

The current classification of farms is based on gross farm sales on an annual basis, not acreage (Reimund et al., 1986). Forty nine percent of our farms are rural resident farms or hobby farms, 22 percent are small family farms, 25 percent are medium family farms, 3 percent are large family farms, and only 1 percent are very large farms. The very large farms, however, are responsible for 31 percent of gross farm sales, with large family farms adding another 18 percent. The hobby farms and small family farms are responsible for only 11 percent of the gross farm sales (Sorensen, 1989b).

Farmers adopt new technologies by going through a five step process (Hoban, 1988). First they have to become aware that a new product exists. This leads to an interest in finding out more about it. They then try it out on a small scale to see if it will work on their farm. They evaluate the results and, if they like what they see, they adopt it for the next growing season. Because of economics, early adopters often make the greatest profit. A profile of an early adopter would look something like this (Hoban, 1988):

—commercially successful operation, large-scale and more specialized than the normal farming operation;
—a sophisticated financial manager, relying on credit;
—looks at farming as a business rather than a way of life;
—tends to have more formal education;
—often more capable farm and business manager;
—highly motivated; willing to take risks;
—well connected to communication networks; and
—tends to be a community opinion leader.

In addition, farmers who respond well to biotechnology are younger than our average farmer (who is 52 years old), better educated (college or beyond), newer to agriculture, and farm more acres with a higher gross income than the average farmer (Bultena and Lasley, 1987).

Farmers are going to need better management skills to more easily integrate technological advances in the future (Ealter, 1985). Extension has always played a major role in educating farmers about innovations. Can our current Extension structure handle this or is additional change necessary?

Suggestions

1. *Site Specific Field Testing:* Extension needs to play an expanded role in conducting on-site tests to determine if new crops or products are well-suited to local conditions. Companies will not have the resources or incentives to do this. A potential problem is whether Extension agents will have access to innovations before they are marketed to farmers (Buttel, 1987b).

2. *Improving On-Farm Management Skills:* Extension should assist limited resource farmers in expanding their management skills. For farmers who don't fit the early adopter profile, it will be important that Extension make an extra effort to make sure they have access to the resources needed for successful adoption of innovations.

3. *Expansion of Interdisciplinary Research:* Dr. Thomas Hoban (1988) presents a strong case for making social science research available to Cooperative Extension Service directors, research administrators, and public policy makers who are interested in evaluating and mitigating the impacts of technology. In particular, there are three areas of inquiry that should be explored:

—*Technology assessment:* Technology assessment tries to identify a wide range of social, political, economic, and environmental consequences that may result from technological change before they happen. Like cost-benefit analysis it weighs beneficial consequences against adverse impacts (Molnar et al., 1987).

—*Social impact assessment:* Social impact assessment includes another related set of useful tools and ideas that could help identity, evaluate, and deal with negative impacts of biotechnology (Freudenburg, 1986). Public participation and education play an important role in this type of assessment.

—*Interorganizational relationships:* This type of research attempts to analyze relationships among organizations and develop mechanisms to insure efficient and equitable collaboration with optimum resource exchange (Rogers and Whetten, 1982). We will need coordination and cooperation from the universities, the Extension Service, and the private sector if the transfer of new technologies is to be successful.

The 1990 Farm Bill

One question we have to ask ourselves up front is whether the 1990 farm bill can handle a subject issue as complex as this or if separate stand-alone legislation would be more feasible from a practical and political standpoint.

Biotechnology can go a long way in alleviating environmental problems facing farmers if we can successfully integrate its resulting products into our farming systems. We need to take a closer look at the relationships among soil erosion and agricultural chemical use, environmental quality, and farm programs (AFBF, 1988; Reichelderier and Phipps, 1988). Are we sending conflicting signals to farmers?

For example, Reichelderier and Phipps quote an unpublished Ph.D. thesis that found that farm programs increase the use of agricultural chemicals by:

(1) Reducing incentives to relocate production to regions with lower economic and environmental costs;

(2) Increasing the production of chemically intensive crops such as corn and cotton; and

(3) Raising the prices of program crops, making the application of chemicals more valuable to the farmer (Miranowski, 1975).

Having said this, it remains far from certain that overfertilization and excessive chemical use is due to our farm programs. Many, if not most farmers, use soil tests and practices that are economically efficient. It is likely that a much stronger correlation exists between use of agricultural chemicals and the weather and market conditions in a given crop-year.

Currently, the six basic program commodities (corn, wheat, rice, cotton, barley, and soybeans) account for 80 percent of pesticide use and four commodities (corn, wheat, soybeans, and cotton) account for approximately 60 percent of fertilizer nutrient use (Wolcott, 1988). For farmers to reduce their dependency on agricultural chemicals in future years (Benbrook, 1989) they must be encouraged to:

—modify cropping patterns and tillage practices to minimize pesticide leaching;

—seek integrated pest management (IPM) systems, pest resistant cultivars, and other novel strategies that reduce the need for agricultural chemicals;

—switch from environmentally damaging chemicals to more benign substitutes; and
—improve the timing and placement of pesticides (a component of most IPM programs).

These goals are achievable. Whether or not we can successfully reach them will depend on whether we can resolve the following issues:

1. *Shifting Priorities:* Presently, the USDA is chasing after water quality protection, biological control, and Low Input Sustainable Agriculture. We are very concerned about the seeming lack of coordination in pursuing what are very similar goals aimed in conflicting directions. A piece-meal approach to solving the very complex problems currently faced by agriculture could make things worse and alienate a lot of people in the process.

2. *LISA in lieu of IPM:* Integrated Pest Management (IPM) programs have a sound scientific basis and a fifteen year track record in protecting the environment while maintaining agricultural viability. Even with convincing evidence that IPM works and works well, farmers are still reluctant to adopt full programs (Grieshop et al., 1988). They prefer instead to adopt individual techniques from IPM programs that they can fit into their current production management operations. For example, they may chose to use crop rotations, plant trap crops, or put out pheromone traps to time spray applications. It has been difficult to convince farmers to abandon proven techniques and replace them with information-intensive pest control strategies that are still evolving (Rajotte et al. 1987; Wearing, 1988). Yet, the USDA now appears to be switching to Low Input Sustainable Agriculture (LISA) without achieving their objective of widespread use of IPM programs (Carter, 1989). LISA lacks a definition, has only 2 to 3 years of hard science behind it, and is even more information-intensive, labor-intensive, and site specific than is IPM. Does that make sense? Best management practices (BMP's) or IPM techniques that can be incorporated more easily into current farming operations would offer a more immediate solution to environmental problems.

3. *Dissension in USDA ranks:* The current lack of communication and coordination within USDA agencies is hurting agriculture. The agencies appear to expend more energy protecting their own turfs and extending their own territories than in working together to provide farmers with ways to deal successfully with the challenges they face. Other Federal agencies appear to be equally territorial. In playing those kinds of games, no one is the winner.

4. *Technology transfer:* We must be able to transfer technology successfully between the research community and farmers on a timely basis. If we can't do this, we will lose more small farmers and our ability to compete on world markets will be severely eroded. We need to ask ourselves if our institutional management structures, with their continual shifts in priorities, can carry us into the 1990's.

5. *Research needs:* Agricultural research must be a priority. The Board on Agriculture recently proposed a $500 million competitive grants program within the USDA to revitalize agriculture. If given equal status with the other agencies in the USDA (e.g. with ARS and CSRS), these novel awards for agricultural ingenuity could go

a long ways in helping farmers cope with the increasing complexities of farming. We would hope that Congress would give serious consideration to this proposal.

Finally, in the 1981 and 1985 farm bills, research and development (R&D) in agriculture was only touched on briefly. If agriculture is to move forward and deal successfully with the complex environmental, social, and political issues it faces, we must encourage R&D in a thoughtful and far-thinking manner.

References

Agricultural Research Institute, 1985. A Survey of U.S. Agricultural Research by Private Industry, III. Bethesda, MD, July 1985.

American Farm Bureau Federation, 1988. 1990 Farm Program Study. The American Farm Bureau Federation 1990 Farm Program Study Committee, August 1988.

Benbrook, C.M., 1986. Pesticide Regulatory Policy: Creating a Positive Climate for Innovation. Conference on Technology and Agricultural Policy, December 12, 1986.

Benbrook, C.M., 1989. Agriculture and Ground Water Quality: Policy Implications and Choices. Presented at "Technical Session on Agriculture and Ground Water Quality," 1989 Annual Meeting of the AAAS, San Francisco, CA, January 17, 1989.

Benbrook, C.H. and P.B. Moses, 1986. Engineering crops to resist herbicides. *Technology Review*, Nov./Dec.: 55–61, 79.

Brosten, D. and Simmonds, B., 1989. Crops gone wild. *Agrichemical Age*, May: 6, 7, 26, 28.

Brown, L., 1988. The growing grain gap. *World Watch*, Sept./Oct.: 10–18.

Bultena, G. and P. Lasley, 1987. The Dark Side of Biotechnology: Farmers' Appraisals of the Benefits and Costs of Technological Innovation. Presented at the Iowa State University Agricultural Bioethics Symposium, Ames, Iowa, November 1987.

Buttel, F.H., 1987. Biotechnology, Agriculture and Rural America: Socioeconomic and Ethical Issues. Presented at the Iowa State University Agricultural Bioethics Symposium, Ames, Iowa, November 1987.

Carter, H.O., 1989. Agricultural sustainability: an overview and research assessment. *Calif. Ag.*, May/June: 16–18, 37.

Crop Sciences Society of America, American Society of Agronomy, and Soil Science Society of America, 1989. An Evaluation of the Issues, Challenges, and Opportunities Related to Plant Patenting, Madison, WI.

Freudenburg, W.R., 1986. Social Impact Assessment. *Ann. Rev. Sociol.* 12: 451–478.

Government Accounting Office, 1986. Pesticides: EPA's Formidable Task to Assess and Regulate Their Risks. GAO/RCED–86–125.

Grieshop, J.I., F.G. Zalom, and G. Miyao, 1988. Adoption and diffusion of integrated pest management innovations in agriculture. *Bull. Entomol. Soc. Amer.* 34(2): 72–78.

Hoban, T.J., 1988. Towards an Understanding of Farmers' Decisions to Adopt Biotechnology and Some Potential Impacts. Presented at the Keystone Environmental, Citizen, State, and

Local Leadership Initiative Regional Workshop, Austin, Texas, July 14–15, 1988.

Joint Council on Food and Agricultural Sciences, 1986. Five Year Plan for the Food and Agricultural Sciences. A report to the Secretary of Agriculture. March 1986.

Keystone Center, 1988. Final Report of the Keystone International Dialogue on Plant Genetic Resources. Session I: *Ex Situ* Conservation of Plant Genetic Resources, Keystone, Colorado, August 15–18, 1988.

Kalter, R.J., 1985. The new biotech agriculture: unforeseen economic consequences. *Issues in Science and Technology* (fall): 125–133.

Miranowski, J.A., 1975. The Demand for Agricultural Crop Chemicals Under Alternative Farm Program and Pollution Control Solutions. Unpublished Ph.D. thesis, Department of Economics, Harvard University, May 1975.

Molnar, J.J., H. Kinnucan, and U. Hatch, 1987. Anticipating the Impacts of Biotechnology on Agriculture: A Review and Synthesis. *In*: Biotechnology in Agricultural Chemistry (ACE Symposium Series 334), Homer M. LeBaron et al., eds.; pp. 254–267, The American Chemical Society, Washington, D.C.

National Academy of Sciences, 1987. Regulating Pesticides in Food: The Delaney Paradox. Board on Agriculture, National Research Council, National Academy Press, Washington, D.C.

National Research Council, 1984. Genetic Engineering of Plants: Agricultural Research Opportunities and Policy Concerns. Board on Agriculture, National Research Council, National Academy Press, Washington, D.C.

National Research Council, 1986. Pesticide Resistance: Strategies and Tactics for Management. Committee on Strategies for the Management of Pesticide Resistant Pest Populations, Board on Agriculture, National Research Council, National Academy Press, Washington, D.C.

National Research Council, 1987. Agricultural Biotechnology: Strategies for National Competitiveness. Committee on a National Strategy for Biotechnology in Agriculture. Board on Agriculture, National Research Council, National Academy Press, Washington, D.C.

Nielsen, E.G. and L.K. Lee, 1987. The Magnitude and Costs of Ground Water Contamination From Agricultural Chemicals. A National Perspective. NRED/ERS/USDA Staff Report AGES870318. Washington, D.C. 53 pp.

Office of Technology Assessment, U.S. Congress, 1988. New Developments in Biotechnology. U.S. Investment in Biotechnology—Special Report, OTA-BA-360, Washington, D.C., U.S. Government Printing Office, July 1988.

Rajotte, E.G., R.F. Kazmierczak, M.T. Lambur, G.W. Norton, and W.A. Allen, 1987. The National Evaluation of Extension's Integrated Pest Management (IPM) Programs. Virginia Cooperative Extension Service Publication 491–010 through 491–024, Blacksburg, VA.

Rattner, M., 1989. Crop Biotech '89: Research Efforts Are Market Driven. *Bio/Technology* 7: 337–341.

Reichelderfer, K. and T.T. Phipps, 1988. A Briefing Book: Agricultural Policy and Environmental Quality. The National Center for Food and Agricultural Policy. Resources for the Future, Washington D.C.

Rogers, D.L. and D.A. Whetten, 1982. *Interorganizational Coordination: Theory, Research and Implementation*. Iowa State University Press, Ames, Iowa.

Silva, D., 1989. The War of the Weeds. *Agrichemical Age*/May: 12–13.

Sorensen, A.A., 1989a. An Economic Overview: Ag Biotech, the Farmer and The Economy. Presented at the Industrial Biotechnology Association Meeting: Food for the World Through Biotechnology, Chicago, IL, May 17–19.

Sorensen, A.A., 1989b. Reconciling Agriculture's Needs With Water Quality. *In:* Water Planning From the Town Up., pp. 37–48. New Mexico Water Resources Research Institute, Report No. 238, New Mexico State University, Las Cruces, New Mexico.

Sorensen, A.A., 1989c. The Future of Pesticides: Small Farmers's Perspectives; Large Farmers's Perspectives. pp. 74–80. *In*: Pesticides: Risks, Management, Alternatives; Proceedings of a Symposium. Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University, Blacksburg, VA.

U.S. Department of Agriculture, 1986. Research for Tomorrow, 1986 Yearbook of Agriculture, Washington, D.C.

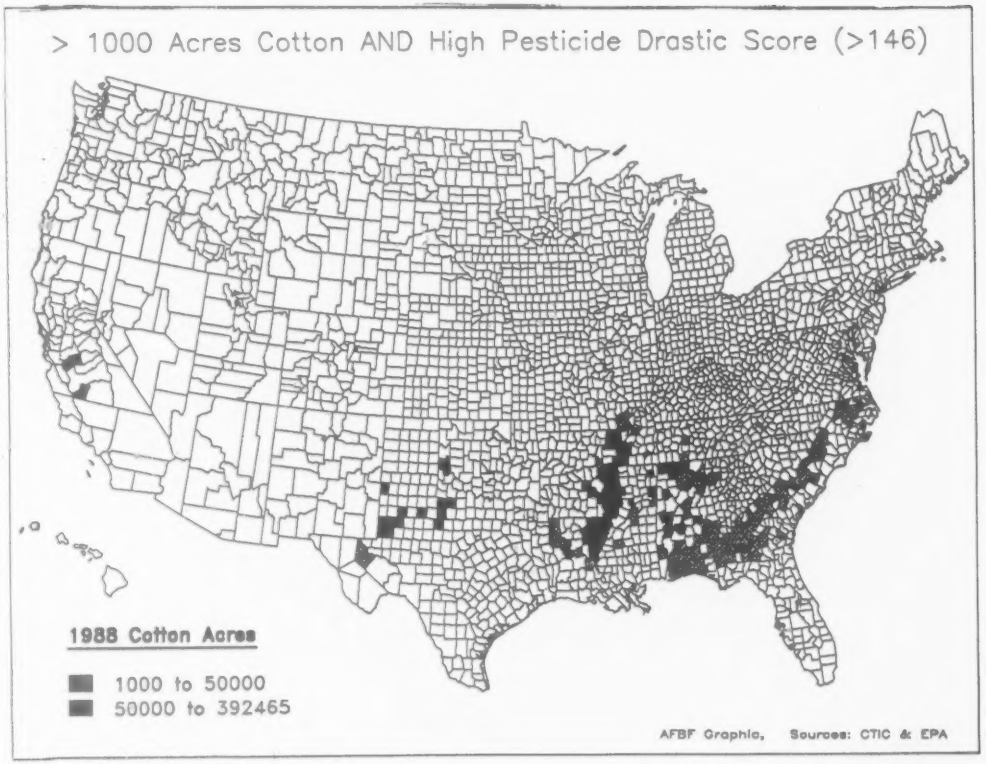
Wearing, C.H., 1988. Evaluating the IPM implementation process. *Ann. Rev. Entomol.* 33: 17–38.

Witt, S.C., 1985. BriefBook: Biotechnology and Genetic Diversity. California Agricultural Lands Project, San Francisco, CA.

Wolcott, R., 1988. Analyzing the Challenge Ahead of Us. *EPA Journal* 14: 31–34.

AREAS OF THE COUNTRY WHERE COTTON IS BEING GROWN OVER GROUNDWATER HIGHLY VULNERABLE TO CONTAMINATION BY PESTICIDES

AMERICAN FARM BUREAU FEDERATION GRAPHIC


> 1000 Acres Cotton AND High Pesticide Drastic Score (>146)
1988 Cotton Acres
1000 to 50000
50000 to 392465
AFBF Graphic, Sources: CTIC & EPA

SUSTAINABLE AGRICULTURE AND THE OTHER KIND OF BIOTECHNOLOGY

(By Jack Doyle, Director, Agriculture and Biotechnology Project, Environmental Policy Institute/Friends of the Earth, Washington, D.C.)

Today, there are really two kinds of agricultural biotechnology, but only one kind, the high-tech kind, is getting all the hype and attention. Another kind of agricultural biology—more consistent with low-input and sustainable practices—is also possible, but is in danger of being eclipsed and pushed aside by the funding and public policies now being directed at high-tech agriculture and biotechnology.

The problem with biotechnology's current direction in agriculture is that it will likely deliver more of the same. That is, on its present course, biotechnology will likely extend and reinforce a whole range of agricultural practices and products that will continue to pose environmental, public health, and economic problems. However, there is still time—with thoughtful public policy—to turn the "new biology" in more a sustainable direction.

High Yield or Maximum Rate of Return?

The central dogma of modern agricultural science and policy for the last 50 years or more has been high yield. The development of hybrid corn in the 1930's and the Green Revolution grains in the 1960's further solidified this approach. Corn yields have increased about one bushel per acre per year since 1930 from an average of about 40 bushels per acre then, to more than 100 bushels per acre today. Similar gains have been made in the livestock sector. Although the U.S. dairy herd has been cut in half since 1950, it produces the same amount of milk on one-third less feed. High-yield production systems also include an array of other inputs that work together to produce the high yield—from fertilizer to specially formulated feeds.

The central question that high-yield agriculture brings to the public policy arena today is: Can it be sustained in its cost to the farmer and its impact on the environment? Can it be sustained in its current high-tech package, with all of its corollary energy and capital requirements?

Today, a midwestern corn farmer spends on the average at least $46 per acre for fertilizer, $17 per acre for pesticides, $17 per acre for seed, and $18 per acre for fuel. Capital investments can be substantial as well. Irrigation investments in the Great Plains have steadily risen over the last 30 years, moving from $103 per acre in 1950, to $201 per acre by 1970, to more than $500 per acre by 1979. Some farmers are now spending as much as $35,000 a year on her-

bicides and $50,000 a year in energy costs to run center pivot irrigation systems which themselves cost about $70,000 each.

What is now made possible with biotechnology in agriculture is a new high-tech orchestration for maximizing production; a system in which chemicals, machinery, and capital all perform together in a synchrony of yield centered on the gene.

But will this system maximize return on investment *for the farmer?* Will it be durable and profitable over time? And will it be a secure source of food production?

Challenging the Conventional Wisdom

William L. Brown, former CEO and Chairman of Pioneer Hi-Bred International, is among a thoughtful group of scientists and businessmen who have begun to raise concerns about high-yield agriculture. In 1984, when he was head of the National Academy of Sciences Board on Agriculture, Brown gave a speech in which he raised some concerns about the vulnerability of high-yield agriculture. "As we offer the farmer increasingly sophisticated and costly technological packages", he said, "we inadvertently exacerbate two related sources of instability in agriculture. High-yield production systems are often more volatile in terms of harvested production, and more erratic in terms of profit for the farmer."

Similarly, Pioneer's CEO Thomas Urban noted in remarks he made a few years ago: "We see farmers who are no longer striving for maximum yield. They're striving for maximum profit. And those are not necessarily the same thing."

Yet challenging the conventional wisdom about high-yield agriculture will not be easy, if only because the basis of high-yield agriculture is "locked in" to the agricultural system by the structure of farm programs, how farm equipment is calibrated and paid for, seed company breeding programs, and the product and marketing orientation of most farm supply industries. In short, high-yield is highly capitalized in agribusiness and by the agricultural research establishment.

However, given the recent consumer uprisings over pesticides in food and water, incidents of farmer and farmworker poisonings, and the rising cost of production, there is a growing and broad base of public support for changing agricultural production systems; particularly those systems that deliver environmental and public health side effects.[1]

---

[1] Public opinion and related activities in a range of quarters in recent years suggest a broadening of support for reducing agriculture's environmental and public health side effects:

Public Opinion. In a January 1984 consumer survey conducted by the Food Marketing Institute, 77 percent of those polled expressed concern over pesticide and herbicide residues in food, indicating the problem to be a "serious hazard". A September 1986 *Des Moines Register* poll taken in Iowa shows that 58 percent of those surveyed believe farm chemicals are the biggest threat to water quality, and that 78 percent favor limits on farm chemicals.

Farmer Opinion. In a September 1986 *Des Moines Register* poll, more than half of the Iowans responding from farm households favored placing limits on farm chemical use. In a similar public opinion poll of 400 Iowans taken in late September and early October 1986 for the Iowa Department of Natural Resources, some 65 percent of farmers and retired farmers favored tighter restrictions on farm pesticides, while 52 percent favored tighter restrictions on fertilizers.

Business Reaction. In November 1986, the H.J. Heinz Co. announced that it was planning to restrict the purchase of crops used in the manufacture of baby foods that had been treated with certain pesticides. Heinz listed 12 chemicals: alachlor, aldicarb, captan, captafol, carbofuran, carbon tetrachloride, cyanazine, daminozide, dinocap, ethylene oxide, linuron, and TPTH. Heinz

Continued

Yet biotechnology appears to be taking agriculture in the wrong direction for instituting such changes.

Biotechnology: Extending the Pesticide Era

Some of biotechnology's first commercial applications in agriculture will be crops that have been genetically engineered to tolerate or resist herbicides. More than half of the field tests of genetically engineered crops so far approved by USDA have been for herbicide resistant crop strains.

Today, there are more than 30 chemical, pharmaceutical and biotechnology companies working to make crops herbicide resistant, an investment of capital and scientific talent that will only further the chemical approach to weed management. Others are working on chemical plant growth regulators that will signal or prompt genes in crops to "turn on" or "turn off" at the right time to control traits such as dormancy, increased flowering or pod set, greater stalk strength, or improved "harvestability". Similar research is being conducted with farm animals, where a certain kind of chemically laced feed would "turn on" the right promoter gene at the right time to begin a growth function, or to bring the animal into fertility, or for some other function.

Such applications of biotechnology are troubling because they suggest a continuation of chemical toxicity in agriculture, increased ground water contamination, more farmer and farmworker poisonings, and increased consumer exposure to pesticides in food. Such applications will "ratchet up" the interplay of technological parts on the modern farm, potentially increasing farm production costs, as well as making agriculture more dependent and more vulnerable to technological failure or supply disruption.

Rather than using biotechnology to prolong the pesticide era, a national effort ought to be launched to phase out pesticides with safe and effective biological methods of pest control.

Better Biologicals Through Genetic Engineering?

While on one level, moving in the direction of biological pest management is a laudable goal, doing so through the genetic engineering of microbes and/or insects may pose new risks should mutations occur or inserted genes be transferred to other organisms.

In addition, engineered biologicals may not be much better or longer lasting than the chemical pesticides that preceded them, particularly if a few strategies employing a few genes are used widely in the environment. Resistance may in fact emerge more quickly than it has with chemical pesticides. In some ways, this approach may only substitute a biological treadmill for a chemical treadmill.

There is, however, another possibility with biotechnology, but one that does not necessarily presuppose the use of genetic engineering. What it does require is the use of common sense and thoughtful biological application.

---

told farmers that it would likely test crops for the absence of these chemicals—all of which were then still legal, but under review by EPA as possible health hazards.

Today, throughout the Nation's land-grant universities, its State agricultural experiment stations, and USDA's agricultural research centers, there is a huge treasure trove of "old biology" and common sense farming practices that has been neglected in recent years. Many of these old and abandoned biological and management techniques have existed since at least the turn of the century.

It is known that certain corn strains which produce thicker-husked ears can prevent worms from burrowing into the ear and damaging the corn; certain kinds of crop rotations can increase the "good bugs" that prey on crop-damaging insects; and some naturally occurring fungi can be used safely to kill certain kinds of weeds. In addition, there is extensive information about soils, microbial ecology, plant breeding, intercropping, insect adaptability, domestication of new crops and livestock, and other strategies—all of which has application now. Much of this information simply needs to be rediscovered; and pockets of good researchers now operating in isolation from one another, and without political or funding support for their good works, need encouragement.

New "common sense" discoveries and applications of old biological controls are also occurring in the private sector.

The Ingene Biotechnology Co. of Columbia, MD has discovered a safe and effective way to kill nematodes. Chitin, a protein formed in crab and shrimp shells, nourishes the growth of soil microbes such as fungi. Fungi, in turn, can convert chitin into an enzyme that destroys young nematodes and nematode eggs. Sprinkling the ground-up crustacean shells on the soil get the job done.

Evans BioControl of Broomfield, CO is using *Nosema locustae,* a natural spore that kills grasshoppers by destroying their fatty tissue. The spore, originally discovered in 1953, is applied to tiny wheat bran specs which can then be sprayed on fields by conventional crop dusters.

Farmers too, with years of practical knowledge and hands-on experience in pest management, are important biological experts in their own right. Many farmers throughout the country are already rediscovering the "old biology" for themselves, cutting their chemical dependency and increasing their profitability while doing so.

What all of this means is that there is a tremendous base of knowledge and expertise in low-input and sustainable agriculture that exists out there, but has not yet been fully galvanized by effective public policy.

Biotechnology vs. Sustainable Agriculture

Sustainable agriculture offers a system of farm production that relies chiefly on working *with* nature, rather than trying to conquer it. The biological and stewardship techniques employed have already demonstrated adequate agricultural returns without locking farmers into an expensive and environmentally damaging array of new farm inputs.

Biotechnology, on the other hand, is *not* sustainable agriculture because it is not "systems biology". What genetic engineering offers agriculture is a "silver bullet" technology; a fix-it approach than does not reflect a truly integrated understanding of the bio-

logical systems that make crop and animal agriculture possible in the first place.

Biotechnology, on this course, will only extend the "invade and conquer" and "replacement parts" style of farm production and pest management. This kind of farming will not be making the natural system work for the benefit of sustained, low-input production. Rather, it will be purposely putting agricultural production on a straight-line course of product-after-product, gene-after-gene, new fix for new problem.

Certainly, there are contributions that a thoughtful "bio-tech-knowledgy" could make to advancing sustainable agriculture, but these have more to do with applying systems management skills than they do in designing products for sale.

It should be possible, for example, to enlighten traditional crop and animal breeding practices with the new knowledge now being generated from molecular biology. New, molecular-level insights into crop/pest interactions, or pest life cycles, should help to enhance the breeder's ability to "build in" more durable forms of disease and insect resistance.

However, researchers should not rush to develop genetically engineered microorganisms to be used as pesticidal agents when a better crop rotation or an insect-resistant crop variety will accomplish the same task more efficiently.

What Congress Can Do

Congress should direct its agricultural research policies and increased funding toward sustainable agriculture rather than biotechnology. This means, in effect, making biotechnology subsidiary to the goals of sustainable agriculture.

Congress should craft a major new initiative to emphasize sustainable and low-input agriculture in the 1990 farm bill; an act that could be incorporated into the research title of the farm bill. Such an act might be called, "The Sustainable Agriculture Research Centers and Extension Act". This act would be based on a new *formula-funded,* matching grant system for the nation's land grant universities and agricultural experiment stations. The idea behind such a major new program would be to offer funding and goals in a new three-prong program:

(1) New research initiatives in low input and sustainable agriculture;

(2) An extension program of existing and new low-input and sustainable practices, technical assistance, and information for farmers; and

(3) A new land-grant education program for undergraduate and graduate students in low-input and sustainable agriculture.

The purpose of this act would be to ensure that new Sustainable Agriculture Research Centers would have an institutional base and receive national policy backing and Federal funding. Perhaps the central goal of this program would be to improve farmers' profitability through the use of low input and sustainable systems. Among the chief environmental goals of the program would be to reduce soil erosion, conserve water, reduce on-farm energy costs,

and reduce chemical contamination of soil, streams, and ground water.

Some possible tasks and charges of a national program for sustainable agriculture could include the following:

• *Inventory Existing Ag System Biological Knowledge Base.* A careful and thorough inventory of the Nation's "agricultural archive" throughout the public sector system would no doubt turn up extensive and useful information about soils, biological controls, microbial ecology, plant breeding, intercropping, insect adaptability, domestication of new crops and livestock, and other strategies. Such information, once collected, should be placed on a computer system and made available to farmers and researchers as public domain information.

• *Make Disease and Insect Resistance a Top Priority.* In the interest of reducing or phasing out the use of toxic agricultural pesticides, the development of durable, host-based disease and insect resistance in all major and minor crops and livestock should become a top priority throughout all USDA, land grant, and agricultural experiment station programs.

• *Institute Major Research Effort in Non-Chemical Weed Management.* Herbicides presently constitute nearly 80 percent of all agricultural pesticide use in the United States. Herbicides are increasingly found in ground water and rural drinking water supplies. Yet, there are a range of alternative weed management strategies that might reduce or eliminate the need for chemical herbicides. Biological weed management strategies—using insects, crop rotations, allelopathy, non-engineered weed pathogens, and other strategies—should be elevated to a much higher level of research funding than they currently receive.

• *Research Nitrogen Cycle and Alternative Fertility Strategies.* Developing biological fertilization strategies that help to reduce, replace, and/or eliminate the use of synthetic fertilizers found jeopardizing public health or the environment should receive more attention in agricultural research programs. All strategies and/or combinations of strategies would be sought, including microbial, crop breeding, and cultural strategies such as crop rotation.

• *Develop Apomictic Hybrids and Open-Pollinated Varieties.* Hybrid crop varieties may be produced asexually through a process called apomixis, a clonal reproductive method known to occur in a number of basic grain species such as corn, wheat, rice, sorghum and alfalfa, and also in citrus fruits. Apomictic hybrids may be cheaper to research and could come to market quicker than conventional hybrids, but since they reproduce asexually, private sector has shown little interest and limited research exists in the public sector. Similarly, some research with open-pollinated lines of some grain species suggests that yields can approach hybrid levels in some cases.

• *Initiate Alternative Crop, Livestock, and In-Field Diversification Research Strategies.* More research and extension need to be undertaken to advance sustainable, "mixed community" crop and livestock systems. New crop and livestock research—including reintroduction of old and rare breeds—is needed to broaden genetic

diversity in agriculture and reduce genetic vulnerability.[2] Such efforts should be funded at a much higher levels than is now apparent in the public sector. Land grants and ag experiment stations should be in vanguard of discovering *new crops* for agriculture—not simply new uses for conventional crops like corn and wheat. Less then 1 percent of today's 300,000 plant species are now utilized in modern agriculture. Agricultural diversification means economic diversification, new businesses, more jobs.

In addition to these few suggested areas of program emphasis, there could in fact, be any number of others, including: selection of faster growing crop species; development of new double- and intercropping systems; research on drought and cold tolerance in crops; better and new feed and forage crops for livestock, including work on native grasses; research on microbial ecology; development of new biological controls; research on alternative on-farm energy systems; and the development of marketing strategies for new crops and/or livestock that encourage sustainable systems.

Clearly, a wide range of research and extension projects could be initiated under a National Sustainable Agriculture Research Program, either on a Center-by-Center basis, or elevated to higher priority by way of a particular national or regional concern.

Scientists, administrators, farmers and environmentalists who have participated in successful State-administered sustainable agricultural research programs—such as the Aldo Leopold Center at Iowa State University and the sustainable program at the University of Maine, for example—should be consulted for their views and ideas about the structure, content and organization of such a formula-based national program.

Public Purpose Charter and Role of the Land-Grant Complex

A second major initiative that Congress should undertake in connection with the 1990 farm bill is to state clearly, as a matter of public policy, the purpose and goals of agricultural research at the nation's land grant universities and State agricultural experiment stations.

Implied in the public funding of agricultural research is responsibility and accountability to the public, as well as a return of public benefits. Traditionally, the benefits of agricultural research have come in the form of an assured and safe food supply and reasonable prices for food, but they may also include stable rural economies, protection of agricultural resources, and minimization of public health costs and environmental side effects that may result from farm production.

As is apparent in their enabling legislation, the land-grant universities and the agricultural experiment stations were established

---

[2] In a 1989 pamphlet from Pioneer Hi-Bred, entitled, *"Genetic Diversity and the Structure of the U.S. Seed Corn Industry,"* it is noted: "A farmer who purchases the top-performing hybrid sold by each of two, three, or more companies may believe he's spreading his genetic risk. The truth is, those two or three hybrids could be the same. And if that's so, he actually may have increased his risk, but he doesn't know it . . ."

". . . Today there are only a few inbred developers who 'broadcast' sell their parent lines to more than 200 seed corn marketing companies, who then grow or package the same or similar hybrids under different brand names and numbers. That creates a very real danger for corn growers.

". . . In our opinion, the loss of genetic diversity is particularly alarming."

to serve a broad social purpose that goes well beyond farmers and improving farm productivity, but extends also to the welfare of the rural community.

It is also clear that the land-grant institutions should have more than just a narrow "workbench" or "efficiency" mission in their various research and extension tasks, and that their constituency is broader than farmers and farm-related business. In the language of the Hatch Act of 1887 and subsequent amendments, for example, there is reference to the "improvement of the rural home and rural life", "the welfare of the consumer", and the promotion of "a sound and prosperous agriculture and rural life as indispensable to the maintenance of maximum employment and national prosperity and security . . ." (7 U.S.C. 361c).

Public sector agricultural research, in this sense, is something available to all, for the general good. "The land-grant university system was established on a public service basis different from that of other universities", explains OTA in its 1986 study, *Technology, Public Policy, and the Changing Structure of American Agriculture.* "Its tradition has implied a social contract that makes its discoveries freely available to the public." Yet if those discoveries are first made available to private commercial interests, which then charge the public whatever those firms see fit, then is the public really getting the benefits at the costs it bargained for in that social contract? [3]

Congress should conduct a comprehensive investigation of corporate research funding at the nation's land-grant universities and State agricultural experiment stations to determine:

(1) How such funding may be affecting the direction and independence of agricultural research;

(2) How such funding may be affecting the farmer's cost of production as compared to alternative products, management practices or information that might be made available to farmers directly through the agricultural experiment station; and

(3) What implications such funding may have for the environment and/or public health and safety as opposed to alternative products or management practices that are not receiving corporate or public support.

---

[3] In addition, some land grants are actively selling their research services to the business community. For example, in the May/June 1989 edition of the magazine *agBiotechnology*, a full page advertisement by Washington State University (WSU) featuring a university researcher looking over some new wheat varieties bears the lead headline: "What This Man Knows About Wheat Could Make You Rich". And the text of the ad reads as follows:

"If being on the cutting edge of agricultural technology could make a difference in your R&D efforts, maybe you should get a little closer to the action.

"What action? How about major advances that have cut a demanding, decade-long developmental methodology in half?

"That's what WSU Agronomy Professor Cal Konzak and his associates have been working on. Now, new and improved varieties of wheat can be released up to six years sooner than ever before. A significant breakthrough.

"Dr. Konzak's expertise in plant herbicide and disease resistance is only an example of how WSU's revolutionary agricultural research might make a profitable impact on your business.

"And the Washington State University Research and Technology Park provide the way to get closer to the action and onto the front lines of your business frontier.

"For more information about how your business can begin taking advantage of agriculture's cutting edge, just call Park Director Larry Simonsmeier toll-free today. You'll be a step closer already."

The New Challenge and New Constituency for Agricultural Research

Today, America's once-premier agricultural research complex—the land-grant universities, the State agricultural experiment stations, and the agricultural extension service—is in decline, and is in danger of becoming irrelevant. In recent years, in fact, some politicians have advocated closing the system down or selling it off piece-by-piece to the private sector. New funding programs now being formulated will take agricultural researchers even farther away from the land-grant system in the future, further weakening its power base. And politically, the system has missed some important chances to build a new base among farmers, environmentalists and consumers.

There is great opportunity for the Congress and the land-grant complex to make beneficial changes for agriculture, the environment, and public health. But a lot will depend on leadership, both from Congress and the land-grant establishment. If the leadership opts to continue to expand the chemical and energy-intensive ways of monoculture based high-yield systems under the cloak of biotechnology, it may only succeed in worsening current environmental and agricultural problems.

On the other hand, instituting a modest National Program in Sustainable Agriculture in the 1990 farm bill—with a formula-based funding mechanism for all States—is a certain way to win the support of agricultural researchers, farmers, environmentalists, and consumers. Surely, urban-based constituencies—consumers and environmentalists especially will support more public funding for sustainable agriculture, particularly research, education, and extension programs designed to reduce synthetic chemical use in agriculture.

STRUCTURAL REFORM

OVERVIEW ON THE NEED FOR STRUCTURAL REFORM IN AGRICULTURAL RESEARCH

(By Dr. William E. Marshall, President, Microbial Genetics Division, Pioneer Hi-Bred International, Inc., Johnston, Iowa)

The submitted papers appear to indicate unanimity among these authors in regards to the need for a significant change in structure, policy and funding of publicly funded agricultural research.

The traditional objectives of agricultural research, which were initially developed during the administration of President Abraham Lincoln, are still appropriate and will continue to be important objectives into the next century. Low cost, safe food, efficient production, will continue to be objectives for our agricultural research community.

Additional New Objectives

However, in addition to these established objectives, we now have several new broad goals which the traditional agricultural research community has not faced heretofore and at present is ill-prepared to meet:

- Lower cost inputs to help improve our competitiveness in world markets,
- Input technologies and management techniques to at least maintain if not regenerate the environment,
- New crops and technologies to help replace fossil fuels as primary sources of energy,
- Research programs for products, processes and techniques that are socially acceptable to the short and long-term needs of rural and urban Americans.

We are fortunate to have available at this same time two scientific breakthroughs that will have a profound influence on our ability to accomplish these new objectives, as well as to allow us to leap forward in progress against the older on-going objectives.

The first set of technologies will be based on the breakthrough in the understanding of the cellular mechanisms of inheritance and development. The second technology will be the gathering and focused use of information for decisionmaking aided by computer usage.

Most scientists would agree that these two opportunities in technology can be, if properly exploited, of dramatic assistance in helping us attain all seven goals—the four new ones in addition to the three traditional ones.

Organizing the Nation's research talent to achieve success in accomplishing these seven goals is as great a challenge as the goals themselves.

How can a system of agricultural research which has performed admirably since 1862 be transformed? How can a network of 125 Federal laboratories and 57 independent State experiment stations accept their expanded role (especially regarding regenerative ecology, the identification of new crop plants and social responsiveness)? How can the system recognize that all Americans (e.g., urban and rural citizens, consumers and environmentalists) are equally important constituents? How can the importance of agriculture be touted politically at the same time when the traditional farmer base of support has dwindled to an insignificant percentage of the population? How to awaken an indifferent populace to the importance of agricultural research in accomplishing these seven goals? On these questions, as well as at the extremes: is any change necessary or can the system change—agreement is not easily reached among researchers, faculty or policymakers.

Three structural issues must be faced before significant headway can be made against the new challenges.

Overcoming Our Inability To Accept the Need for Change

The willingness to respond to the call for change will be spotty and will tend to mirror the institutions' ability to profit financially from the change. Institutions that have a basic science capability will agree that biotechnology (using the broadest definition) will play a major role in agricultural research. Those without such a capability will reject the premise, not from disbelief but from an inability to compete on a new playing field. Since elected representatives tend to reflect the same views as their constituents' land-grant university's college of agriculture, public debate may be heated.

The need to overcome the reluctance to accept change should be focused more on the Cooperative State Research Service (CSRS) and its constituency, the land-grant colleges of agriculture than against the Agriculture Research Service (ARS). In addition to performing research, our agriculture colleges and the experiment stations educate future researchers and provide debate on public policy issues. They are more pervasive and have a greater presence in our society. The Agricultural Research Service (ARS), on the other hand, is a line organization responsive to the Federal Government. Their involvement in education and public policy is slight relative to CSRS and their direction is less divided.

It is a serious mistake of judgement to assume that all colleges of agriculture and their State agriculture experiment stations have equal capabilities to meet the four new challenges or to adapt to biological research or computer-aided decisionmaking. Most of our colleges of agriculture have lost their basic science departments to other colleges on the campus. These basic departments; biochemistry, botany, genetics, microbiology, physiology, are on the campus but outside the colleges of agriculture. The few colleges of agriculture that continue to house the university's premier basic science departments are well poised technically to take on the new challenges. However, fewer than 20 of the 57 State agriculture experiment stations and their colleges of agriculture are prepared to

meet this challenge. The majority will therefore find applying biotechnology very difficult without a significant structural change.

Correcting the Relative Weaknesses in Curriculum Training

The second structural hindrance may be the college of agriculture Ph.D. graduates themselves. Only 60 percent of the Ph.D.'s in agriculture research today graduated from a college of agriculture. Two obvious reasons may be responsible for this shift, and there are no doubt others. The graduate record examination scores (GRE) of agriculture graduate school candidates are among the lowest of all incoming graduate students, and therefore presumably lower than the 40 percent of the Ph.D. workforce in agriculture that graduated from other colleges. Secondly, the new technology base in agriculture is biological in nature. As stated above, training in the basic sciences is weak within most of our colleges of agriculture. This trend suggests that agricultural research needs brighter employees more broadly trained.

Helping the Faculty to Speak Out on Nonfarm Issues

And finally, the faculty themselves are reticent to debate social issues. Their training and careers may have been restricted to a narrow definition of agriculture which has not included ecology, the basic sciences or the social sciences. In the future, training in agricultural research will require training in all these fields.

How To Get Started

Given these objectives and structural impediments, what can be done to broaden the thinking and to more broadly introduce biological research into our traditional agriculture research system?

First, our land-grant colleges of agriculture need to accept as bona fide institutions of agriculture research those institutions presently conducting fundamental biological research in animals, plants and microorganisms, but are not land-grant colleges of agriculture.

Second, the three key elements necessary to tie together the applied approaches of our colleges of agriculture, the fundamental sciences in biology and the social sciences need to be brought together in a coordinated approach to problem solving. Two-way or three-way joint programs between faculty members from agriculture, the biological sciences and the social sciences should be given high priority for Federal funds. This will force both the education in social awareness and the needed influx of biological research into agriculture. (It is assumed that computer literacy is pervasive in all colleges.)

Third, the roles and responsibilities of the Joint Council and Users Advisory Board need to be updated and altered to more accurately reflect research in the 90's. The Joint Council and the Users Advisory Board could become key instruments for monitoring and assisting these changes if their membership and role were recasted.

The shortcoming of the Joint Council as presently constituted is that only the land-grant colleges of agriculture are represented and that the Council reports to its own funding agency—the USDA's

Science and Education. The original purpose of the Joint Council as expressed in the farm bill of 1977 was, to represent the producers of agricultural research and to report progress against objectives to Congress and the administration. Today, however, half of the Federal investment in agricultural research is being invested outside the Joint Council's sole constituency—the land-grant's colleges of agriculture. The researchers who receive these funds are not represented on the Council. And the funding agencies are across a number of nonrepresented Federal departments.

The Users Advisory Board suffers in that it is isolated from any administrative branch of the government. It is seen as a stepchild of Congress rather than a part of the administration's management effort. Also its members tend to represent themselves and their personal interests.

The Joint Council membership needs to be broadened to include representation from institutions in addition to those within the land-grant universities' colleges of agriculture to include those that also conduct agriculture research (e.g., NSF, DOE, NIH). The Council will be strengthened by membership from among those scientists engaged in agriculture research who are not on the faculties of land-grant colleges of agriculture, e.g., State colleges of agriculture, private universities, and non-profit institutions.

The Users Advisory Board needs members that represent groups of farmers, ranchers, operators, rather than individuals representing their individual points of view.

The two Boards, consisting of 25 members each need to be fused together under one directorate, independent of any Federal research granting agency. The directorate should report to the Secretary of Agriculture, independent of its Science and Education Agency. The Boards would jointly issue reports summarizing all Federal funds for agriculture research, comment on the appropriateness of the investment and monitor progress against national objectives. They would, of course, be authorized to commission studies and would be responsive to the needs of their constituencies in helping them meet the national objectives.

Of utmost importance is that our land-grant colleges of agriculture recognize that the scientific base of research is shifting away from underneath them to include our colleges of sciences. If the Joint Council is unable to broaden its thinking and membership, we will soon have competing and conflicting groups representing agriculture research. Of equal importance is their acceptance of the broadening of their client base from farmers and ranchers to include consumers and environmentalists.

The traditional system under CSRS needs outside help to remain the nucleus of the national system. A newly constituted Joint Council and Users Advisory Board can be important change agents.

A third group would also seem to be necessary—an interdepartmental committee on agriculture research. Representatives from the USDA, NSF, DOE, NIH, AID, responsible for funding research for agriculture, need to coordinate their policies. The need for joint proposals uniting the fundamental sciences of biology with the applied research of agriculture would be an immediate topic on their agenda.

The scientific base and the clientele base for agriculture is shifting. Out institutions need to reflect these changes. Leadership can be provided at the national level.

22-829 - 89 - 7

REINVESTMENT IN FOOD, AGRICULTURE, AND ENVIRONMENT RESEARCH CAPABILITY: NEED FOR A NATIONAL INITIATIVE

(By Charles M. Benbrook, Executive Director, Board on Agriculture, National Research Council)

Agricultural research issues hardly registered a footnote in the 1981 and 1985 farm bill processes. Hopefully this farm bill cycle will be different, given the compelling need for a major infusion of new money and talent into the programs and institutions supporting food, agriculture, and environment research. It is important for Congress to reassure firmly the Nation's commitment to research, education, and technology development and transfer because knowledge and human skills are the Nation's most truly inexhaustible and renewable resource.

The country is already beginning to pay a price for our failure to creatively reform agricultural R&D policy—including our commitment of public funding—during the 1980's. We are now less capable of dealing with contemporary and emerging problems of food safety, resource conservation, nutrition, developing new crops and uses; and the Congress is once again beginning the process of writing omnibus farm legislation with a sometimes poor understanding of basic trends and forces that have an impact on major national objectives (education, competitiveness, the environment). We also are collectively uncertain about the role of science and technology (S&T) in responding to (or overcoming) those trends and forces, nor do we have a firm sense of what changes in S&T policies and programs are needed to more fully exploit our strengths in the future.

The need for a national initiative for research in the food, agricultural and environmental sciences is based on a simple but powerful premise:

> *As a Nation we can and must more fully and profitably use our productive capacity. While doing so, we must more diligently serve as stewards of our natural resources, and create and take advantage of new opportunities to improve the health of all citizens through safer, more nutritious foods.*

Fortunately, the sector's economic performance is now improving. Nonetheless, volatility in prices and surpluses, government program costs, and profitability remain as significant concerns.

In this dynamic context, there are clearly several emerging challenges that could have profound impacts on farmers and foresters, the food industry, and agribusiness. The Nation has a major stake in how effectively we meet the challenges arising from consumer worries about food safety, the desire of people to meet nutritional goals, and the hope that production and environmental goals can

be balanced. Other papers in this volume address these issues in greater detail.

The Board on Agriculture, in a recent report calling for a major national agriculture, food, and environment research initiative, surveys a range of tangible goals which S&T can help the Nation attain. In the case of some goals, scientific advance is a prerequisite to make it even feasible to attain desirable objectives. Substantially reducing microbiological and mycotoxin contamination, and hence the rate of incidence of certain foodborne illnesses is an example. In other cases, goals can be reached by more effectively tapping technology and resources that are currently available. Here, the Board stresses the need for new policies, improved and more dynamic markets, and new management systems and analytical skills. Water quality protection is an example discussed at length in our report.

As the Board assessed the need for a publicly funded research initiative, several individuals asked the Board to consider whether it was feasible or realistic to expect the private sector to play an even more important role in advancing the Nation's agricultural, food, and environmental science capability. They wondered—why public money? We addressed this legitimate question by carrying out a detailed assessment of private sector R&D trends and prospects. Two important conclusions emerged:

- Despite the private sector's key role in agricultural and food industry R&D, agribusiness is unlikely to markedly expand R&D commitments in the 1990's. Indeed some retrenchment is viewed as more likely unless agricultural markets and production volume continue to grow for several years in a row without a return to surpluses and production control programs.
- The focus and priorities of private sector R&D do not readily accommodate several of the most important emerging areas of R&D that must be pursued aggressively to solve contemporary challenges: management systems, analytical tools, improved policies, diversification of cropping systems and developing new uses, etc.

Accordingly, the Board concluded a major publicly funded initiative was needed to serve as a catalyst and bridge—a catalyst within the entire food and fiber system, a bridge across sectors, among disciplines, from one college to another on a given campus, from traditional applied agricultural scientists to basic scientists in disciplines removed from but relevant to food and fiber system challenges.

There are many ways to justify a major increase in public funding for agricultural research. The two most compelling economic arguments are that the economic return to public sector R&D investments is clearly very high—about 30 percent return per year, spanning the 20- to 30-year active life of a new technology. A rich body of analytical work supports this conclusion. Consumers gain this return, not in the form of a dividend check, but at the supermarket checkout counter—and in a myriad of improvements in well-being and the quality of life.

The second economic justification is that society will be investing billions each year in:

- Conserving natural resources.

- Regulating chemical contaminants.
- Monitoring and advancing food safety.
- Improving nutritional status.
- Subsidizing farm inputs and exports, and supporting farm income.
- Treating avoidable human disease, and compensating individuals and companies for the loss of productivity caused by illness.
- Fostering economic development.

Our record in many of these areas is worrisome. Public and private costs—already in the tens of billions—are rising sharply, often with marginal benefit. Public expectations continue to evolve, seeking even greater margins of safety, as well as progress toward several other goals—as long as food costs do not rise.

It is clearly the role of government to seek out and support any current investment with the ability in the future to make these challenges and public needs more readily attainable or markedly less expensive to attain, particularly when such investments promise to yield benefits that are self-sustaining over a long period of time and are not likely to be made by the private sector. Science and technology—strategically focused and properly (and quickly) applied—clearly could be such an investment. But how might our publicly funded research institutions be challenged—and supported—in moving S&T ahead in areas of national need? What is the most appropriate funding mechanism to meet contemporary needs?

First, the Board recognized that States will continue to play a critical role in funding problem-solving, more applied work at State agricultural experiment stations; and that States are likely to continue targeting additional funding to special needs and opportunities, like Iowa's Leopold Center for Sustainable Agriculture; the Agricultural Issues Center, and Pacific Rim trade research in California, and Florida's research in the environmental fate of pesticides. Few States are likely, however, to have the fiscal resources needed to make substantially greater investments in longer-term, basic research and technology development. Accordingly, if the public sector is to underwrite a broadening of the Nation's S&T, the Federal Government must take the lead. State resources will still play a critical role in supporting the educational, technology adaptation, and systems-related activities essential for new S&T to find effective and profitable commercial application. For the same reason Federal formula funded programs should also be sustained, as must the key R&D programs of the Agricultural Research Service.

An expanded Federal role in support of agricultural, food, and environmental R&D must be structured to help the Nation achieve critical goals (briefly discussed above). It must do so by:

- Exploiting the rapid, exciting advances in S&T, and targeting S&T advance toward areas of great opportunity.
- Attracting new talent into agricultural, food, and related R&D.
- Fostering more rapid progress throughout the system, in all phases of discovery, technology development and transfer, and market and policy change.

The Board concluded that the most cost-effective way to meet these needs was through a major increase in the U.S. Department of Agriculture's competitive research grants program. This pro-

gram currently supports about $40 million in research annually, just 4 percent of USDA research expenditures. It supports work in only three areas: plant sciences, animal productivity, and human nutrition. Support in each of these areas is far too limited to make much of a difference in the $2 billion Federal-State research enterprise.

The Board concluded that at least 35 percent of USDA research support should be allocated through competitive grants. While far less than the 80 to 90 percent reliance on competitive grants in other leading Federal science agencies (e.g., the National Science Foundation and National Institutes of Health) an expanded USDA competitive grant program distributing 35 percent of the Department's research funds would exert strong influence on scientific direction and interaction throughout the system.

Currently, USDA's research expenditures are just under $900 million ($544 million for ARS, $352 million through CSRS, FY 1988). For the reasons noted earlier, these programs must be maintained, indeed strengthened, as the competitive grant program grows from $40 million to $500 million. Once the $500 million goal is reached, competitive grants would allocate just under 35 percent of the $1.4 billion in USDA research support ($900 million currently plus $500 million in competitive grants).

An expanded USDA competitive grant program should be structured to support research in six major program areas including:

- Plant productivity;
- Animal productivity;
- Nutrition, food quality, and health;
- Natural resources and environment;
- Engineering, products, and processes; and
- Markets, trade, and policy.

Offer four types of grants:

- Principal investigator;
- Fundamental multidisciplinary team;
- Mission-oriented team; and
- Research-strengthening.

- Provide more realistic levels of support and lengths of grants ($100,000 per year per principal investigator, for 3 to 5 years).
- Emphasize multidisciplinary research by allocating up to 50 percent of available funds through the two types of multidisciplinary grants.[1]

The Nation's food and agricultural science institutions and programs are sound, and have compiled an impressive record of service to the Nation. Now, the challenges facing the system are changing and exciting new areas of scientific and technological advance are emerging. It is growing much more difficult to maintain a competitive edge in global markets, a key need if the food and fiber sector of the economy is to help the Nation diversify economic opportunity, and balance the twin deficits (Federal budget and trade deficits).

---

[1] For further details on these program recommendations, see the Board on Agriculture, NRC report calling for a national initiative in the agricultural, food, and environmental sciences. By Natural Research Council, "Investing in Research a Proposal to Strengthen the Agricultural, Food, and Environmental System." ©1989 National Academy Press.

Science and technology can be thought of as a resource, much like cropland and capital. It can be abused and depreciated, or conserved and developed. When coupled with the Nation's abundant natural resources human talent, and public and private infrastructure, S&T can bring into reach a food and agricultural system that meets both social expectations and competitive challenges in the years ahead.

COMPETITIVE VERSUS FORMULA FUNDING: ASSESSING THE RISKS AND BENEFITS

(By Donald L. McLean, Dean and Director and Catherine W. Donnelly, Associate Dean and Associate Director, College of Agriculture and Life Sciences, University of Vermont)

There is an ongoing debate with respect to the ideal model which should be used when allocating Federal funds to Agricultural Experiment Stations for the support of agricultural research. The Hatch Act stipulates that Federal funds to support agricultural research are to be allocated through the use of a formula which is based upon a State's rural and farm population relative to the total U.S. rural and farm population. Critics of this model charge that this method of resource allocation fails to take into consideration either the research needs of a particular State, or the research capability possessed by a particular institution. Critics of the current model favor allocation of Federal funding to support agricultural research solely on a competitive basis. Others argue that awarding funds strictly on a competitive basis will undermine the continuity of agricultural research and will ultimately favor the wealthier States which already possess extensive facilities and personnel to support ongoing agricultural research.

The allocation of resources to support agricultural research based primarily upon a State's rural and farm population is a policy which is widely criticized. This formula assumes that States having the largest rural and farm population should be the recipients of the lions share of agricultural research funding. No consideration is given to the quality of the science performed in a given State, nor the number of full time equivalent (FTE) research scientists at a given Experiment Station, nor the nature of a particular agricultural problem inherent to a given State or region. Small institutions with reduced scale, but nevertheless excellent research facilities, are penalized because of the size of the rural and farm population.

The idea that research institutions must be large to perform excellent research is a fallacy. The State of Vermont has the largest per capita percentage of rural population in the United States. But, as a small State we thus receive a disproportionately small share of resources. The quality of science performed at the University of Vermont is high, however. For example, the University of Vermont Medical School is small relative to other U.S. medical schools, ranking number 76 in size. Yet in spite of its size, the UVM Medical School faculty ranks number 4 in the Nation with respect to per capita receipt of extramural research funding. This example speaks to the fact that an institution may be small yet able to offer high quality research capability.

The real issue faced by all States, no matter how large or small, is how to maintain an ongoing agricultural research infrastructure in light of declining Federal support for agricultural research. According to Nipp (1988) the real issue stems from the fact that ". . . Federal money spent for agricultural research has held nearly constant over the past 20 years, while it has increased in most other areas." The U.S. agricultural research system in its entirety is feeling the effects of many years of diminished funding to support ongoing research. At many institutions, traditional agricultural program areas are being phased out and resources are being allocated toward biotechnology and other programs of research which are perceived as being more appealing in their fundability. Nationwide, agricultural laboratories are in need of major overhaul, and research equipment is in need of modernization. The bottom line is that all institutions are coming to the realization that formula funds will simply not support agricultural research to an extent consistent with the expectations of the users of agricultural research information.

The generation of research information useful to the Nation's farming community is typically problem solving in nature. Researching agricultural problems can be extremely time consuming, and it may take many years to assemble adequate data on the performance of a disease-resistant apple cultivar or the effects of acid precipitation on forest decline. As agricultural problems become increasingly complex in scope, solutions to these problems will only come through a concerted multidisciplinary approach to problem solving. Thus, insuring the safety of the Nation's food supply, for example, will require the cooperative efforts of food microbiologists, toxicologists, plant scientists, veterinarians, animal scientists and engineers. Resolving a research issue such as the safety and benefit of bovine somatotropin (bST) is more complex still, requiring research input from dairy scientists, veterinarians, plant scientists, nutritionists, endocrinologists, as well as economists and sociologists in an examination of the integral socioeconomic issues. The current State Agricultural Experiment Station (SAES) system enables a multidisciplinary approach to problem solving within an extended time period during which the continuation of research funding is essentially assured. If the current SAES system were dismantled, the infrastructure to support interdisciplinary agricultural problem solving over time would disappear.

By mission, Agricultural Experiment Stations are committed to concentrate research foci upon problem solving. In contrast, competitive research awards are allocated to solve problems of narrow focus within a specific and usually short time period. It is highly unlikely that problem solving research will occur in a competitive realm. The benefit of awarding research dollars on a competitive basis is the assurance that the most qualified and most deserving scientists will be the recipients of scarce research resources. Within the SAES system of increasingly diminishing resources, research awards should be given to those most deserving and meritorious programs of research at the expense of the less active and less essential research programs. However, the danger of awarding research dollars totally on a competitive basis is that needed areas of research with clear benefit to the agricultural community will be

overlooked in favor of more glamorous and fundable research foci. We must devise a system of resource allocation which protects research of a problem-solving nature.

Under the auspices of increasing public and congressional scrutiny, it is clear that Agricultural Experiment Stations will be held increasingly accountable for the way in which formula funds are managed, allocated and spent. It is also clear that we must advocate a system of resource allocation which protects problem solving research while at the same time strives to achieve excellence by making scientists within this system competitive to receive extramural research awards.

In Vermont, we have initiated a resource allocation policy which will give priority awarding of Hatch funds within our Experiment Station to those investigator's who are able to match these resources with outside funds. This system will not discourage problem solving research; rather, problem solving research will be strengthened because Hatch monies will be available under a system of internal competition which assures that the most needed research problems are addressed by the most qualified scientists within our Experiment Station. This creates a system of internal allocation based on merit. Scientists at our Experiment Station are expected to look for competitive funding to augment their programs of research.

Currently, the USDA Competitive Grants Program offers competitive awards in narrowly defined and restricted research areas, which does not facilitate the greatly needed problem solving research. If the USDA Competitive Grants Program were expanded to include broadly defined awards within both the biological but also the social sciences as well, and specifically targeted to problem solving research, quality agricultural research within the SAES system would be greatly improved and assured. While there are no ideal models under which to allocate research funding, in the agricultural research realm the ideal model would protect formula funds which assure the maintenance of an essential research infrastructure, while providing competitive funds to assure that the most important research topics are addressed by the best and the brightest of our SAES scientists.

References

Nipp, Terry L., 1988, Congress and the future of agricultural research, extension and education. J. Prod. Agric. 1:187–190.

CHANGES NECESSARY FOR THE UNITED STATES TO COMPETE IN AN EXPANDING GLOBAL AGRICULTURAL ECONOMY

(By William R. Furtick, Agency Director for Food and Agriculture, Agency for International Development)

I am deeply concerned about the complacency in American agriculture. We have been leading for so long, we just assume this will persist. As a result, we are about to go through the same trauma as the automobile, electronics and other U.S. industries. We must sound the alarm in time to avoid this pending disaster.

With the U.S. farm bill up for a 5-year renewal in 1990 and the U.S. Foreign Assistance Program undergoing study for major revision, now is the time to examine our agricultural programs from the global context which they operate. To ensure that U.S. agriculture will compete in an expanding global market place 10 years from now, we must take the necessary steps today to both diversify and modify our agriculture policy. In order to progress we need to examine what is likely to happen globally in agriculture over this time span. Because an accurate forecast is limited by unknown factors such as new technological breakthroughs, major economic changes and significant political changes or disruptions, we have to base such forecast on the best facts and trends available.

Competition Will Increase

Several trends outside the United States indicate that American agriculture will face growing competition from abroad. Western Europe has risen from a net importing market a few years ago to one of the major agricultural exporters today. Western Europe now competes through a highly subsidized agricultural production and export program. Both public and private sectors have invested heavily in agricultural research. During the next 10 years, Western Europe will undoubtedly become a highly efficient agricultural competitor of the United States. The same will probably be true in Eastern Europe which is endowed with large areas of fertile farmlands. They, too, have invested heavily in research and are rapidly moving toward privatization. A research driven, open-market agricultural economy in Eastern Europe would give rise to another major exporting competitor. Brazil is opening up vast new farmlands with the use of the latest technologies. Agricultural research outside the United States has burst forth over the past few years and broken the U.S. monopoly on high technology agriculture. The primary growth in agricultural research in the United States is in the private sector, but this is being matched by at least equal investments by multinational companies in Europe and other industrial countries.

Increased Demand Due To Population Growth

Global population growth will continue for several decades regardless of how rapidly family planning spreads in the developing world. This trend has been well documented by the United Nations Family Planning Association. During the next 10 years, world agricultural production will need to feed the equivalent of an additional Japan each year. These new mouths will be heavily concentrated in the world's poorest countries, mainly in the tropics. Whether they produce the needed food, purchase it from exporting countries, or receive it as food aid is an important consideration.

The Impact of Rising Incomes

The number of people living in absolute poverty in relation to total world population growth has been steadily decreasing. This is particularly true for Asia where the majority of poor people live. Even in Latin America, where heavy debt burdens and mismanaged economies are resulting in major structural adjustments, incomes, overall, have improved. As income increases and people move out of poverty, their food consumption steadily increases; but there is also a marked change in both the quality and diversity of diets. The shift is away from cereals and other starchy basic commodities to more meat, vegetables, fruit, edible oils, and sweeteners. This rather dramatic shift in Asia is causing local meat shortages and rapid increase in production and importation of meat and feed grains. These feed grain imports are supplying burgeoning poultry and swine industries or are used to feed fish in a developing aquaculture industry. Barring unforeseen events, these trends should continue and escalate. Africa is also experiencing these changes, although this continent has seen the least reduction in poverty. The rate of income growth will be heavily determined by overall international economic trends, the level of investment in agricultural development by donors, and the resolution of the debt crisis that affects mainly Latin America and Africa.

Industrialization Will Place More Demand for Feedstocks and Energy Derived From Agriculture

The trend of rising incomes is resulting in rapid industrialization and increased imports to satisfy the growing demands for energy and manufactured goods of all kinds. The industrial feedstocks and other basic ingredients of this manufacturing boom are increasingly being derived from agricultural products. This is also true for countries like the United States with both indigenous sources and the financial capacity to import petroleum as the major source of industrial feedstocks. An increasing amount of the U.S. corn and soybean crops are being utilized for industrial purposes rather than for food and feed. Those newly industrializing countries that are without domestic sources of petroleum and that experience a high demand on their foreign exchange find it very appealing to utilize locally grown agricultural sources for the needed industrial feedstocks and energy. The United States should greatly increase its investment in industrial utilization research to share in this expanding new market.

Air Pollution and Other Environmental Concerns Encourage Use of New Energy Sources

Rapid urbanization is occurring on a global basis. By the end of this century, the worlds largest cities will all be in developing countries. Nearly all the large urban centers are choking on poor air quality due to combustion of fossil fuels by vehicles, powerplants, etc. This pollution not only creates human discomfort and health hazards in the urban centers, but also results in deterioration of the upper atmosphere that may lead to global climatic changes. Countries like the United States that have vast resources of natural gas can shift to this source of energy for powerplants and as a substitute for gasoline and diesel fuel for vehicles through use as liquid fuel. An increasingly more attractive alternative is use of ethanol and methanol derived through fermentation of plant materials. Brazil has demonstrated this option, both to reduce use of foreign exchange to import petroleum and as a means of cleaning up the air in its large cities. Their experience is being increasingly studied by cities and governments all over the world.

How Will These Growing Needs Be Filled?

Inevitably, the shift to greater use of cereals as feed grains to fill the demand for higher quality diets and the huge potential demand for industrial uses of agricultural commodities will create rapidly growing demands for increased production. The question is who will fill these demands and how? With current technology, the United States and other exporting countries could substantially increase their production if the demand and price structure were favorable. There have been serious questions raised about the potential of the developing countries. The "green revolution" has about reached its maximum potential and maintaining existing yield levels of rice and wheat appear to be a major challenge. Some are very pessimistic about the capability to obtain a substantial new increase in yield levels. There are those in the United States and other industrial countries that question the sustainability of current production levels based on high input agriculture. U.S. farmers are already farming with a heavy use of equipment, agrichemicals, fertilizers and other inputs, much of it made or developed abroad.

The current volume of world agricultural output has been the direct result of heavy global investment in agricultural research. The best illustration of this has been the "green revolution" in wheat and rice lead by multidonor investments in research at the International Wheat and Maize Research Center in Mexico and the International Rice Research Institute in the Philippines. The first high-yielding varieties of wheat and rice were introduced by these two International Agricultural Research Centers (IARC's) in 1965 and 1966; many studies suggested that the new rice technology package typically yielded 40 percent more than the traditional varieties and practices it replaced, while in the case of wheat the increase averaged about 100 percent. However, keeping up with the increased demand that can readily be forecast will require not only significant new research investments, but also different types.

Utilization of New Biotechnologies and Computer Based Sciences

It appears that the past agricultural advancement obtained through traditional plant breeding and increased use of agrichemicals has nearly come to an end for most of the major world crops. There is good potential for gains in a variety of neglected crops, but they are of lesser importance and impact. The significant advances in global agricultural production have been derived from a few basic food crops such as wheat, rice, corn, sorghum, millet, and potatoes and various pulse legumes such as soybeans, peanuts, beans, chickpeas, and pigeon peas. In several of these crops, there has been no yield increase demonstrated during the past 10 or more years. Production gains have been the result of increased adoption of the improved varieties and inputs needed to maximize yield potential. Although there is still some potential for gain through increased adoption of existing technologies, most of the suitable agricultural land is already being utilized with the help of the improved technologies. The real potential lies in the new wave of high technology based research, utilizing computers and biotechnology to further increase crop yield. Beyond yield increases, these new technologies will improve the stability of yield by reducing the impact of climatic variables and losses from pests and diseases. Further, these technologies will enable research scientists to design plants and animals that produce the industrial feedstocks and fuels needed by an industrializing and urbanizing global society. This is an area of research that justifies significant new investments so industries are guaranteed continued supplies of energy and feedstocks as petroleum reserves decline and as a means to avert further environmental deterioration.

Expansion of Production Area and Better Use of Less Well-Endowed Lands

During the past decade, harvests have outpaced population growth, not only because more land has been brought under the plow, but because different plant varieties, more irrigation, fertilizer, and improved tools and equipment allow farmers to produce more from each hectare of land and each hour worked. Most of the more productive lands or those that can be irrigated have been fully utilized with modern production technology. Therefore new production increases will have to come either from new technologies that increase the yield of these primary production areas or by finding means of overcoming the constraints that have limited or prevented cultivation of the much larger areas of less well-endowed or marginal lands.

There is mounting evidence that the opportunity to expand productive lands is very large. Perhaps the most significant potential is in the vast acid savannahs in the tropical areas of Latin America, Africa and to a lesser extent in Asia. The area of unutilized acid savannah land in Brazil, Venezuela, Columbia, Ecuador and Peru is nearly equal to the size of the agricultural lands of the United States. Recent technological developments now enable these areas to produce as much corn and soybeans per acre as the best lands in the United States. The initial capital investment is high,

but this is offset by very low land values. In addition, most of these land areas can produce two crops per year, which is twice the annual capacity of U.S. farmland. There are major, but less dramatic potentials in Africa and Asia. These acid savannahs are also potential competitors for U.S. agriculture. Because of the greater insect, disease and fertility problems of the tropics, their sustained production will be dependent on adequate research to maintain productivity. Developing these new technologies for the acid savannahs has been led by the highly developed national agricultural research system of Brazil (EMBRAPA). In cooperation with private Brazilian companies, EMBRAPA has greatly increased the Nation's competence in agricultural research and exploitation of the huge regional savannahs; prospects for increased and sustained production seem excellent.

In addition to currently unutilized savannahs, vast areas of less well endowed agricultural lands have yet to experience yield gains made possible by science and technology. These are illustrated by the vast areas of upland rice with yields at very low levels, but which represent about seventy percent of the total area growing rice. These large acreages produce less than half the total rice production. There is good reason to believe the gap in yield between irrigated and upland rice can be greatly reduced in the future through high technology research. The same is true for the humid tropical and vast semi arid areas.

The Declining Role of U.S Public Sector Agricultural Research

U.S. agricultural production has been research driven by one of the largest and most effective research systems in the world. The U.S. system for many years dominated global agricultural research and trained a high proportion of the worlds' agricultural scientists. However, during the past two decades a large and creditable global agricultural research system has developed that dwarfs the U.S. system. It is one from which the United States is increasingly isolated and excluded by its own policies, funding methods, and complacency. From a dominant role 30 years ago, the United States has dropped to a minor contributor to global agricultural research with only 7 or 8 percent of the non-private sector scientists in the huge global system that has developed. The problem is not only that the United States has less than 10 percent of the world's scientists supporting an increasingly competitive global economy, but also the United States has largely isolated itself from this cutting edge research network and its discoveries.

During the past few years the United States has gone from a major exporter of new agricultural technology to a net importer. This change in our traditional role has been substantiated by Dr. R.E. Evenson of Yale University in his study based on the source of patent filings and imports. Because of our low relative number of scientists, this trend should rapidly escalate and during the next 10 years we can expect to import most of our new technology. The problem this presents in our efforts to remain competitive is being able to capitalize on the first use of new technology. Since this technology is being increasingly developed abroad, we must link

into its development through collaborative research or risk the consequence of becoming second users of the latest technology and thus forfeiting our competitive edge. At present, the other industrial countries are providing substantial funds to link into the global system to ensure their competitiveness. The comparable U.S. investment is negligible. For relatively small investments in collaborative research with the global system, the United States can gain the full benefits and remain at the forefront by utilizing new technology and thus continue as the world's most efficient producer of agricultural products to fill a rapidly growing and diversifying market.

What Is the Most Cost Effective and Efficient Method of Linking Into the Global Research System?

To determine how the U.S. research system can use its strengths and incorporate the added research capacity of the larger global system requires examination of the current U.S. agricultural research system. The U.S. system has been based on the land-grant university system which focuses on local needs with major support from State appropriated funds. The national needs and the cross cutting issues have been addressed by influencing the university experiment station system by a significant amount of Federal funds passed through to the State experiment stations on a formula basis set by the Hatch Act and by the Agricultural Research Service of the USDA. The basic means of steering the U.S. agricultural research system to address priority problems has been through this allocation of Federal funds and the requirements of the State matching funds. I propose that the Hatch Act funds be increased by 25 percent with the increase used to fund international collaborative research projects in priority areas with foreign research organizations. I also propose that these collaborative research projects be funded on a competitive basis and that State matching funds be required. An equivalent increase must be provided to the Agricultural Research Service for the same purpose. Because the future agricultural innovations will be determined by basic and high technology based research on biotechnologies, and computer based and other technologies, I propose that the budget of the National Science Foundation should be increased for use in competitive grants for collaborative international research between U.S. institutions and those in the international research system. These funds should be equivalent to the increase in Hatch Act funds allocated for more mission oriented research.

Linkage With International Agricultural Research Centers (IARC's)

One of the most dynamic components of the global research system is a network of 25 global and regional research centers funded on a coordinated basis by the international bilateral and multilateral donors. This research system currently has an annual budget of about $300 million. The United States through the Agency for International Development funds about 18 percent of this total. Because this system has become the focal point of germplasm collection and new technology development for the major

world crops, i.e., wheat, corn, rice, sorghum, barley, millet, potatoes, grain legumes, livestock, and a variety of other tropical food crops, the European donors not only contribute significant funds to the IARC's, but also make major linkage contributions to their own research institutions. The United States has provided only insignificant linkage funds to U.S. institutions.

These linkage funds not only funnel new technology back to the donor countries, but also provide an avenue for their scientists to be employed by these centers. Overall, the European donors contribute about three times as much money to their own institutions for collaborative linkages as they provide to fund the IARC's. To rectify this disparity, the United States through AID should expand its current minimal linkage programs to one similar to the European donors. The proposed mechanism would be a linkage program of $150 million per year to be disbursed by AID as competitive grants to U.S. institutions.

Coordination of the New Global Collaborative Program

The U.S. domestic agricultural research system has never had strong central coordination mechanisms. This has had both its strong and weak points. The great agricultural diversity of the United States has been best served by a highly decentralized system. Increasingly, major national goals have been coordinated by expanded use of highly targeted competitive grants as the mechanism. The difficulty, however, has been establishing the priorities that the competitive grants should address.

For the expanded international linkage program, I propose that the National Research Council of the National Academy of Sciences be funded to increase the capacity of the Board on Science and Technology for International Development (BOSTID) to coordinate the setting of a U.S. international research agenda. These research priorities would be determined in close collaboration with USDA, NSF, AID, and the U.S. agricultural agencies and research institutions in both the public and private sector, along with appropriate international organizations and institutions.

Maintaining and Enhancing the U.S. Investment in International Agricultural Development

There is clear evidence that the growth market for both U.S. agricultural commodities and industrial goods is in the developing countries where rapid population growth is occurring. The economies of most of these countries are still largely agricultural. In order for these countries to expand economically, the agricultural sector must be the driving force. There is a direct relationship between the rate of growth in the agricultural sector of developing countries and their expansion in import of American agricultural and other commodities. These relationships and the future potentials of developing countries as U.S. markets have been thoroughly documented by the International Food Policy Research Institute (IFPRI), the Economic Research Service of USDA and a number of American universities. The evidence is quite clear that the interests of U.S. agriculture are better served by continuing and increasing investment in the agricultural development programs of

AID and encouraging the international and private development banks to give priority to agricultural development loans. As the pace of global disarmament increases, it would make sound investment sense to channel some of the savings from decreased military assistance into agricultural development, both foreign and domestic.

The U.S. University System Must Be Internationalized

Like U.S. agricultural research, the educational focus of U.S. universities has primarily a domestic orientation, even though it trains a massive number of foreign students. If the U.S. private sector and the domestic agricultural research system are to be able to employ American graduates with an essential international understanding and perspective, the universities will need to "internationalize" their curriculum. This should include graduate research that can be at least partially done abroad under faculty that have international experience through involvement in international collaborative research projects. The employment options for these students should be expanded by U.S. participation in the United Nations Junior Professional Officer programs that provide a major entry into the international organizations and collaborative graduate training and post-doctoral programs of the international research centers that form the basis for selection of future staff. The international agencies, industries and research centers once had large numbers of American staff and thus American influence. This is rapidly disappearing. The United States needs to regain involvement and experience in order to compete in the international market for agricultural products and agricultural technology that will grow rapidly in the next 10 years. It is up to the agricultural leaders and the U.S. Congress to ensure that the United States does not lose its agricultural competitiveness.

Policy Recommendations

- Increase Hatch Act funds by 25 percent that are earmarked for competitive grants for collaborative research with foreign research institutions.
- Involve the Federal research scientists in this effort through a similarly earmarked 25 percent increase in the ARS budget.
- Match the Hatch Act funds with a similar increase in the funds of NSF for support of basic and strategic collaborative research.
- Link U.S. scientists, through collaborative research, into programs of the IARC's by establishing a $150 million competitive linkage grant program in conjunction with the AID program that supports the U.S. contribution to the IARC's.
- Increase greatly the funding of the current pilot program of U.S. support for the U.N. Associate Professional Officers program administered by the Office of International Cooperation in Development in USDA.
- Strengthen the funding of the agricultural development programs of AID.
- Provide additional funding to BOSTID to coordinate the establishment of national research priorities for international initiatives.

AGRICULTURAL RESEARCH AS SOCIAL PLANNING: SETTING AGRICULTURAL RESEARCH PRIORITIES TO ADVANCE SOCIAL GOALS

(By Chuck Hassebrook, Center for Rural Affairs)

Agriculture research is a form of social planning. Choices made by Congress, research institutions and researchers about what research is undertaken in part determine what farming systems, varieties and technologies are developed, become cost effective, and are put to use. These technologies, in turn, profoundly shape our economic and social structures, the natural environment and human health. If we are to achieve the kind of society we want, these decisions must be made with consideration of broad social and environmental goals. If we are to be a truly democratic society, the public must gain control of these decisions.

Unfortunately, many land-grant research programs are not guided by any broad set of public purposes, leaving a void to be filled by private companies with product development interests. For example, land-grant institutions have been scrambling to develop research programs in biotechnology, but few have defined agronomic or social goals for such research (Buttel, 1986). In the absence of clear public purposes, private parties often leverage public research funds and the time of public sector agriculture researchers to advance their private interests through grants and consulting arrangements with, equity interest in, and employment by biotechnology companies (Buttel, 1986). Many land grants now view royalties from patents and fees as a source of income to support research (Burkhardt, et al., 1987), creating pressure to direct agricultural research toward development of products to sell to farmers. What may be lost in the shuffle is research which helps farmers cut input costs and consequently offers little profit potential to agribusiness corporations (Buttel, 1986). As for consideration of the structure of agriculture in setting research priorities, the University of California and National Association of State Universities and Land-Grant Colleges recently argued in court that land-grant experiment stations have no obligation under Federal law to consider impacts on small family farms in setting their research agenda and a California appellate court agreed (Court of Appeal of the State of California, 1989).

Goals and Purposes of Public Agricultural Research

The establishment of priorities for public sector research plays too large a role in shaping society to be left to individual scientists and product development interests. If agricultural research is to advance broad public purposes, Congress must take the lead by ar-

ticulating the appropriate goals and purposes. Those goals and purposes should include the following:

—*Maximize the number of opportunities for self-employment* in agriculture and rural communities and enhance an economic and social structure free of great inequality. A substantial body of sociological research indicates that a dispersed farm structure with many owner operated farms creates healthier communities than a large farm structure. A University of California researcher summarizes these findings as follows:

> As farm size and absentee ownership increase, social conditions in the local community deteriorate. We have found depressed median family incomes, high levels of poverty, low education levels, social and economic inequality between ethnic groups, etc., associated with land and capital concentration in agriculture. . . . Communities that are surrounded by farms that are larger than can be operated by a family unit have a bi-modal income distribution with a few wealthy elites, a majority of poor laborers, and virtually no middle class. The absence of a middle class at the community level has a serious negative effect on both the quality and quantity of social and commercial services, public education, local governments, etc. (MacCannell, 1983)

—*Prevent environmental contamination and resource depletion.* Over 170 million acres of U.S. farmland are eroding faster than new soil is formed, threatening long term food production potential and contaminating surface waters (USDA, 1987). (This data predates implementation of the Conservation Reserve Program and consequently may be overstated by 25 to 30 million acres.) A 1985 U.S. Geological Survey study revealed that 20 percent of the Nation's wells are contaminated by nitrogen fertilizers (Madison and Brunett, 1985). More than 25 percent of Iowa's population is using drinking water that contains pesticide residues (Hallberg, 1986). To date, the Environmental Protection Agency has found 74 different pesticides in the ground water of 38 States including Nebraska (EPA, 1988).

—*Enhance human health.* While much attention has been focused recently on issues of food safety, growing evidence of the impact of modern farming practices on the health of farmers has received relatively little attention. Numerous epidemiological studies have shown a strong correlation between various types of cancer, especially leukemias, and farming or living in agricultural areas (Strange, Krupicka and Looker, 1984). Studies by the National Cancer Institute and the University of Kansas indicate that farmers who are exposed to herbicides for more than 20 days each year are six times more likely than nonfarmers to develop cancerous tumors known as non-Hodgkins lymphomas (*The Furrow,* 1988).

—*Enhance the resiliency of our food and fiber system.* "U.S. oil production is poised on the edge of a sharp dropoff" and with that dropoff, the United States "may be unable to export food much beyond the year 2000" (Gever, et al., 1986). Likewise, U.S. agriculture is vulnerable to potential rainfall reductions associated with global warming. Although the impact of global warming on rainfall patterns is most uncertain, some climatologists predict that the "greenhouse effect" will shift rainfall north and east away from the Nation's best soils, moving unirrigated corn production out of most of Illinois, Iowa, Kansas, Missouri, Nebraska, and the Dakotas in 50 years (Decker, 1985).

—*Enhance efficiency and maintain our competitiveness,* as we address social and environmental concerns.

Can the Nation's public agricultural research system advance each of these goals simultaneously? I believe that it can do so, but it will not, unless we fundamentally change both current directions in agricultural research and the ways in which research priorities are established.

Industrial Versus Sustainable Systems

Much of the current public research program pursues an industrial approach to agriculture, which is inimical to rural social well being and environmental quality. These systems seek efficiency through reducing the role of people in agriculture, both quantitatively and quality, to make it possible for fewer people to farm the Nation's land and produce its food and fiber. They seek to reduce the amount and sophistication of labor involved in farming to make it possible to more completely separate labor from management and the exercise of judgment to facilitate provision of farm labor by unskilled and low paid employees. These systems use technology, such as chemical and biological products, to override the pest and nutrient constraints on monocrop systems, such as continuous corn. While research may yield new and safer products to over come these constraints, industrial systems will remain vulnerable to the development of resistance by pests and the resistance of natural systems to monocropping and biological uniformity. Likewise, these systems will remain on a treadmill on which new products are needed on a continuing basis to respond to such developments. And for the foreseeable future, these products will continue to present health and/or environmental risks.

By contrast, if we want agriculture research to advance each of the goals set forth above, I believe it can do so, but only if we take a fundamentally different approach to agriculture and technology. That approach is sustainable family farm agriculture, in many respects a more sophisticated and more knowledge and management intensive system than industrial systems.

Sustainable systems seek efficiency by enhancing the role of people in agriculture and making it possible to reduce capital expenditures and input use through more intensive application of skilled labor and hands on management. Whereas industrial systems seek to reduce costs by replacing $2 worth of time with $1 worth of inputs, sustainable family farm systems seek to improve efficiency by replacing $2 worth of inputs with $1 worth of time. Because these systems rely on sophisticated and highly motivated labor able to exercise judgment in the field and barn, they are well suited to an owner-operator structure. These systems require a better understanding of natural systems to enable farmers to adjust their management practices to work in concert with nature, to avoid problems and reduce the need for inputs. They typically involve practices such as crop rotation and cover crops to meet nutrient needs, reduce pest problems, conserve soil and reduce vulnerability to drought.

Several examples illustrate the alternative research approaches appropriate to these two systems. In the area of weed control, no

focus of research has recently received more attention and more research dollars than the development of herbicide resistant crop varieties. Such varieties would allow farmers to use a greater number of herbicides to provide more complete weed control chemically, and thereby eliminate the need for mechanical cultivation, allowing one person to farm more acres. This is exemplar of the industrial approach. By contrast, a sustainable agriculture research focus would be the development of more cold tolerant crop varieties, which germinate and emerge faster in cool spring temperatures to get ahead of weeds and allow for more effective weed control without chemicals through light tillage, such as rotary hoeing and row cultivation. The former seeks to reduce costs by reducing the role of the farmer. The latter seeks efficiency by enhancing the role of the farmer to reduce purchased input use.

In the area of insect and disease control, industrial systems are supported by research to create new products for farmers to buy to control the pests that plague monocrop systems, such as corn rootworm, grey leaf spot and head smut in continuous corn (corn produced on the same land year after year). By contrast, sustainable agriculture would be supported by research in the field of agroecology, aimed at developing an understanding of the interactions between living organisms, environmental conditions and farming practices in agricultural ecosystems. Such research would provide the knowledge base for farmers to use their skills and management to alter practices and farm in concert with nature, to avoid pest epidemics. Plant breeding efforts supportive of sustainable agriculture would focus on developing resistance to those pests which are not adequately controlled by economically acceptable changes in farming practices. Researchers would develop new uses for the crops added to rotations in sustainable systems, such as oats and alfalfa, to make these rotations more profitable.

In livestock production, millions of dollars of public funds have been spent to refine industrialized total confinement production systems for hogs and other livestock, and to address diseases and other problems which occur in these systems. By their very nature, total confinement systems move meat and milk production off of moderate sized owner operated farms. The high investment costs preclude small scale application and the routinization of labor and management tasks in these systems is conducive to employee operation. For example, it costs twice as much per cow to build confinement facilities for a 52 cow dairy as for a 600 cow dairy (Buxton, 1985). Lower investment facilities are a better alternative to moderate scale producers. A University of Tennessee study found that hogs could be produced more cheaply in a moderate investment farrow-to-finish system than in a high investment total confinement system (Johnston, 1984).

A sustainable family farm research agenda in livestock production would focus on development of lower investment livestock production systems which reduce capital barriers to small and beginning farmers and allow them to earn a return on their skilled labor and the intensive hands on management that such systems require. Disease and breeding research would focus on overcoming the stresses in such systems, including parasites and temperature variation. Researchers would seek to improve the nutritional con-

tent of the crops grown on diversified farms to reduce the need for feed supplement purchases. This would reduce the significance of the economic disadvantage smaller farms face in buying feed inputs. Small hog producers pay much more for their feed supplements than larger producers (Van Arsdall and Nelson, 1985).

Policy Recommendations

The highest priority for the research title of the 1990 farm bill should be articulation of the goals and purposes of the Federal investment in agricultural research, including formula funds, competitive grants and other Federal agricultural research funds. Those goals and purposes should include those presented earlier in this paper for the structure of agriculture, human health, farm resiliency and environment. Procedures should be defined by Congress to ensure that these goals and purposes are reflected in the research priority setting process. That should include requiring an annual report of the Agriculture Research Service and each land-grant experiment station describing its efforts to incorporate these goals in its research priority setting process. In addition, the the USDA Joint Council and Extension Users Advisory Board should report annually on how they have incorporated these goals in their plans and recommendations.

With respect to competitive grants for agricultural research, Congress should direct the administering bodies, including USDA and the National Science Foundation, to incorporate these goals both in their calls for proposals and criteria for evaluating proposals. That may require giving them the authority to spend a portion of their funds on research to assess likely impacts of alternative research directions. The result might be calls for proposals that list areas of research deemed to be especially appropriate, and criteria that reward research in such areas. For example, a call for proposals might give priority to basic research in agroecology or research aimed at gaining a basic understanding of specific pests for which no economically viable low input solution exists.

New Spending

Any new funds for agricultural research should be likewise targeted, including the Board on Agriculture proposal to increase appropriations for competitive grants for agricultural research by $500 million per year. Any increased authorization should include the following:

—*Increased funds to the Low Input Sustainable Agriculture Research Program (LISA).* Any new funding should substantially be directed to this program which has a strong track record. The LISA proposal review process, which includes scientists, farmers and nonprofit sustainable agriculture organizations, provides for decisions reflecting sound science, farmer needs and social and environmental considerations. The program is grossly underfunded relative to the cost of quality proposals submitted. Current fundings levels are adequate to support fewer than 10 percent of the proposals submitted.

—*Funds for a strong agroecology research program.* As stated by Texas A&M University plant pathologist J.A. Browning, "There is

a great dearth of research from an 'agroecosystem approach' which would enable farmers to choose, from among the many interacting cropping systems and farming practices, those that work together to produce the desired result" (Browning, 1985).

—*Funds for genetics research on development of crop varieties and livestock* of potential value in addressing pests and other constraints which cannot be controlled at an acceptable economic cost, by changes in farming practices.

—*Funds for research on farming in an uncertain climate.* While predictions of reduced rainfall from climate change are uncertain, it would be wise to step up research efforts to prepare us for the possibility, including breeding more drought tolerant plants; development of management systems to maximize populations of beneficial mycorrhizae fungi, which help plants better utilize soil moisture; and development of management practices to reduce evaporation and increase water absorption including rotations, tillage systems, field windbreaks, organic matter management and cover crops.

—*A directive that "calls for proposals" and evaluation criteria which reflect congressional goals* and purposes for agricultural research, as discussed above.

—*Allocation of a portion of the new research funds to assessment of the social and environmental impacts of alternative research directions.*

—*Allocation of a portion of new funds to competitive grants for innovative extension programs* to reach small and moderate sized farmers, including potential beginning farmers, and minority farmers who might otherwise be left behind by rapidly changing technology. We are entering the era of information intensive agriculture, as we make greater use of biotechnology and low-input sustainable systems. Whereas in recent years those who lacked capital were left behind, in coming years those who lack information will be left behind (Harshbarger, 1987). If society wants to protect a base of small farm operators, it may be necessary to undertake a major extension effort to develop their management capabilities (Kliebenstein and Shin, 1987). The content of the program should include a major focus on low-input and low investment systems appropriate to farmers with limited capital. The program would include procedures for identifying research needs of participating farmers and feeding those into the land-grant research priority setting process.

—*Allocation of a portion of the funds to competitive grants for innovative programs to engage the public in the debate* over the future of the food and agricultural system and involve them in setting agricultural research priorities.

New Uses and New Crops Research

Authorization of new funds for research to find new uses for existing crops and to develop new farm crops with market potential should give priority to the following:

—*Research which develops new crops and new uses* for existing crops which, when added to rotations, reduce soil erosion and use of petrochemicals and other purchased inputs.

—*Development of production systems suitable to small and moderate sized family farms* for new crops and development of new uses for existing crops grown principally on such farms. For example, USDA'S efforts to develop aquaculture should focus on low investment systems which work on family sized farms.

—*Development of modest scale processing techniques* appropriate to location on farms and in small rural communities and development of new crops suitable to small scale processing, to support rural development.

Finally, such authorization should provide for representation of sustainable agriculture groups on any appointed body controlling or advising the use of such funds.

Water Quality Research and Extension Efforts

The farm bill should direct that USDA and EPA research and extension efforts on water quality include a strong sustainable agriculture component. That might include research to evaluate the effectiveness of low-input sustainable agriculture approaches in addressing water contamination and special demonstration and educational programs on low-input sustainable agriculture in areas with water contamination problems. It might also include the development of best management practices for manure and legume sources of crop nutrients.

Conclusion

If the public agricultural research system is to yield a desirable structure of agriculture, vital rural communities, a resilient food system, and environmental and human health, Congress must clearly articulate these as the public purposes the system is to serve. Those who serve in the system must accept the responsibility of directing their research toward the advancement of public purposes democratically defined.

To fail these challenges risks continued erosion of public support for the land-grant system and science. People forced to choose between a research system and technologies which produce results that are neither desirable or necessary, will reject the system and technology itself. We must instead gain public control of research and technology to direct them toward advancement of social well being and service of broad public purposes.

References

Browning, J.A., 1985, "Plant Disease and Nematode Control," Background Paper for *Technology, Public Policy, and the Changing Structure of American Agriculture,* OTA

Burkhardt, Jeffrey, et al., 1987, "Biotechnology and Food: A Social Appraisal," in *Food Biotechnology,* Dietrick Knorr, Ed., Marcel Dekker, Inc., New York.

Buttel, Fred; 1986, "Biotechnology and Public Agricultural Research Policy," in *Agricultural Science Policy in Transition,* James H. Rhodes, Editor, Bethesda, MD.

Buxton, Boyd M., 1985, "Economic, Policy, and Technology Factors Affecting Herd Size and Regional Location of U.S. Milk Production," Background Paper for *Technology, Public Policy, and the Changing Structure of American Agriculture,* OTA.

Court of Appeal of the State of California, May 25, 1989, *California Agrarian Action Project, Inc., et al.* v. *Regents of the University of California et al.;* First Appellate District, Division Five.

Decker, Wayne L., 1985, "The Implications of Climate Change for 21st Century Agriculture," The Farm and Food System in Transition: Emerging Policy Issues, USDA—Extension, Washington, DC.

EPA, May 1988, Pesticides in Ground Water Data Base.

Gever, John, et al., 1986, *Beyond Oil,* Ballinger Publishing Co., Cambridge, MA.

Hallberg, George, Nov./Dec. 1986, "From Hoes to Herbicides: Agriculture and Ground Water Quality," *Journal of Soil and Water Conservation,* 41:6.

Harshbarger, C. Edward, Feb. 1987, "Financial Survival in an Era of Technological Change," *Journal of Agribusiness.*

Johnston, Gene, Nov. 1984, "Mid-Cost Hog System Shows Most Profit," *Successful Farming.*

Kliebenstein, James and Seung Y. Shin, 1987, "Impact of bST on Dairy Producers," Dept. of Economics, Iowa State University.

MacCannell, Dean, 1983, "Agribusiness and the Small Community," Background paper to *Technology, Public Policy and the Changing Structure of American Agriculture,* Office of Technology Assessment, U.S. Congress, Washington, DC.

Madison, R.J., and Jilann Brunett, 1985, Overview of the Occurrence of Nitrate in Ground Water of the United States, U.S. Geological Survey Water Summary 1984, USGS Water Quality Paper 2275.

Strange, Marty, Lis Krupicka and Dan Looker; 1984, "The Hidden Health Effects of Pesticides," in *It's Not all Sunshine and Fresh Air,* Center for Rural Affairs, Walthill, NE.

USDA, 1987; The Second RCA Appraisal.

Van Arsdall, Roy N. and Kenneth E. Nelson, Dec. 1985, "Economies of Size in Hog Production," Economic Research Service, Technical Bulletin No. 1712, USDA.

NATIONAL PEER REVIEW OF FEDERAL AND UNIVERSITY AGRICULTURAL RESEARCH FACILITIES

(By Jack Marvel, Chairman, the National Agricultural Research and Extension, Users Advisory Board)

INTRODUCTION

The National Agricultural Research and Extension Users Advisory Board (UAB) is mandated to provide "user" recommendations to those who shape Federal programs in agricultural research, extension and higher education. UAB makes these recommendations in annual reports which are submitted to the administration and Congress.

During the past 10 years, more than 80 members of the UAB have traveled throughout the Nation to visit Federal and university agricultural research facilities. Our site visits provide better understanding of our facilities' missions, their successes and challenges as well as serve as the basis for recommendations on funding levels and ways to strengthen programs.

The UAB believes that our agricultural research laboratories are a national asset. We are certain that these facilities have and will continue to play an essential role in solving the challenges agriculture is facing today.

Our visits and study, however, have made us aware of some problems. When the UAB appraises proposed budgets for agricultural research and extension we see decreasing budget allocations and greater interdepartmental competition for these limited dollars. Simultaneously, a plethora of State and congressionally initiated requests for facilities have surfaced but new construction money is rarely in the executive budget request. Consequently, the UAB has concluded that a good review system that evaluates *all* the facility requests is needed. A single review system for all facility requests will ensure that the money appropriated is optimally utilized by building an agricultural research system based on merit.

The UAB has been concerned with facility construction and research allocation decisions for many years. In its first report, in 1979, when discussing the Federal-State research system, the UAB said "we are not satisfied that responsibilities are defined, allocated, performed or accounted for with sufficient precision and adequacy among Federal and State units." In 1982 the UAB endorsed efforts to reduce or terminate mandated and unreviewed ARS facilities. The 1983 report expressed the concern that the lack of external critical evaluation (peer review) of research grants was the cause of significant agricultural research budget increases in programs outside the U.S. Department of Agriculture. Further, the

UAB supported the closure of regional research locations considered by the Department as unnecessary. In 1986 the UAB agreed that ongoing evaluations were perfunctory most of the time and recommended external peer review for Federal and State research. In 1987 the UAB expressed its concern and made recommendations about the peer review process to evaluate potential State Agriculture Experiment Station research projects, utilizing Federal funds, before funding and to monitor the research progress. In the 1988 report the UAB recommended that external, expert peer review be mandatory for all Agricultural Research Service research and recommended the closing or consolidation of excess laboratory facilities. This recommendation was repeated in the 1989 report.

These recommendations were made because the UAB, over the years, saw:

(1) Facilities that were badly in need of repair;

(2) USDA-supported facilities that were only marginally related to agriculture;

(3) Facilities that were mandated but the UAB did not deem necessary;

(4) Facilities that stood either underfunded or understaffed or both;

(5) Facilities that lacked an adequate supply of expertise; and

(6) Facilities that were conducting out-dated or low-priority research programs.

This is not to negate the many excellent facilities UAB has reviewed. It is to say, in our opinion, construction that bypasses merit review often comes at the expense of existing facilities which need repairs and improvements. Studies estimate the infrastructure repair bill to be about $10 billion and dwindling resources leave too little new money even for the research itself. Moreover, based on estimates from Universities, approximately $226 million is needed to complete building projects started in 1987, 1988, and 1989.

The UAB believes that the funding, construction, and continued existence of an agricultural research facility should be justified by the research mission, not by the availability of industry-supported technology or the desire for a state-of-the-art facility in a particular location.

The UAB, in previous reports, has called for an *independent critical review system* to improve the efficiency and effectiveness of our Federal and University research efforts in agriculture. Today, in responding to the Senate Committee's request for a "facility review," UAB is recommending a complete procedure *to provide needed review and evaluation of Federal and University facilities in the agricultural research system. This comprehensive review and evaluation process would provide the merit upon which facility funding would be awarded.*

External Peer Review Panel

The UAB believes that to maintain the finest agricultural research facility program in the world, this Nation must develop a means of evaluating such facilities. First we must develop an overall, cohesive strategy for agricultural research and then we must

determine if our existing or proposed agricultural research facilities are or will adequately fulfill the strategy's long range goals and objectives.

To undertake this evaluation, the UAB recommends the establishment of a National External Peer Review Panel. The Panel would be an arm of the USDA and members would be appointed by the Secretary of Agriculture with recommendations from the Chairman and Ranking members of the Senate and House Agriculture Committees, National Academy of Science and other user, academic, and agri-industry organizations. It would be composed of individuals from both the public and private sector with expertise in science, engineering, management, research and development, and technology transfer. Panel members from Federal or University facilities being considered by the Panel would necessarily be excused from that particular evaluation and merit assessment. Administrative support should come from research agencies at USDA to carry out the duties of this Panel.

The purposes of the Panel would be:

- To evaluate the status and progress of existing Federal and University agricultural research facilities and make a merit assessment for the Secretary of Agriculture and the Congress; and
- To evaluate and make merit assessments of proposed Federal and University agricultural research facilities for the Congress and the Secretary.

External Peer Review Teams

In addition to the Panel, the UAB recommends establishment of several External Peer Review Teams. The purpose of these Teams would be to conduct on-site evaluations of existing and proposed Federal and University agricultural research facilities. Expenses for the Team evaluation would be incurred by the Facility submitting the proposal or being reviewed. These evaluations would be submitted to the Panel for the merit assessment being conveyed to the Secretary and the Congress.

The Teams would include individuals from the public and private sector in science, engineering, finance, business management, marketing and like fields with expertise in science/technical merit, management, research facilities and technology transfer. Team members of Federal or University facilities being reviewed by the Team would necessarily be excused from that particular evaluation.

Strategic Planning

A number of actions would be necessary prior to the Team evaluations and merit assessments of the Panel:

- Development of clear and concise mission statements for all existing and proposed facilities;
- Development of a 5-year written plan for all existing and proposed facilities which describes the organization, where it is going, and how it is going to get there. This strategic plan would be used for management purposes and to facilitate evaluation of performance and would be updated annually;

• Development of a standard outline which each Facility and Proposed Facility would follow in producing its strategic plan which would be provided to the Panel.

The Strategic Plan would reflect the unique combination of the Facility's interest and capabilities, and would discuss features of the Facility in sufficient detail to be evaluated in accordance with the guidelines and criteria.

The UAB recommends that the National Science Foundation (NSF) Guidelines for proposed Science and Technology Research Centers (NSF–STRC, NSF 87–75) be utilized in a modified form that would address existing and proposed Federal and University agricultural research facilities.

Each Strategic Plan should contain the following elements and additional subsections:

Executive Summary

Clear descriptions of the Facility, its intellectual theme and its distinguishing features should be provided.

Rational for the Facility

The following questions should be answered: Why is the Facility needed? What difference will this Facility make within the context of the total resources and Facilities available in the United States? What other Federal or University facilities are conducting similar research? How does this Facility relate to similar Facilities in the Nation, Region or State?

Description of the Intellectual Focus and Research

A Facility's intellectual theme should be sufficiently long-term to justify it. The Facility must have sufficient focus to have definable goals. The proposed research goals and activities should be described in adequate detail to allow assessment of their scientific merit and the need for use of the Facility mode of research. In addition, the anticipated effects that activities carried out at the Facility will have on agriculture should be stated.

Educational Features of the Facility

What is the Facility's means of attracting high quality scientists or engineers? Information about scientists available to staff the facilities should be provided.

Knowledge Transfer, Outreach and Participation

The Facility must have clearly defined plans for involving and transferring knowledge to the agricultural community.

Management Plan

The management plan must describe the organizational structure of the Facility; and the mechanisms for focusing activities, selecting and integrating related research projects, and allocating funds and equipment.

Physical Structure for the Facility

A description of the available space and/or plans for new or renovated space, major items of equipment, maintenance requirements, and the estimated costs should be included.

Institutional and Other Sector Support for the Facility

Details of committed and expected support from all sources should be provided.

Budget

A proposed 5-year budget for the Facility must be provided.

Impact of the Facility Upon the Nation's Economy

How has or will the Facility contribute to agriculture's economic growth?

Biographical Sketches and Individual Support

A short biographical sketch and a list of the most recent and/or significant publications and activities of the key personnel with a summary of the participant's current and pending research efforts should be provided.

CRITERIA

Facilities should be evaluated through a multi-tier merit review process. The first stage of review would be conducted by the External Peer Review Panel to assess adherence to the guidelines and preconditions for Federal and University facilities, including the scientific and economic development impact of the Facility. This phase of the review process may involve both ad hoc mail and panel reviews.

The full review process would involve a comprehensive review by the Teams convened for the sole purpose of evaluating existing and proposed Facilities. During the course of the review process, each Facility would receive a site visit review. Site visit reviewers would consider all aspects of the organization, including the facilities, scientific and technical staff, the mechanisms planned for the management, and ongoing evaluation of the work at the research Facility.

Facilities and proposed facilities would be reviewed by the Teams to determine their ability to meet goals of Congress and the Secretary of Agriculture. Emphasis would be placed upon the extent to which the Facility has enhanced, or would enhance the economic well-being of U.S. Agriculture. The review should ascertain if the Facility meets or can meet the national standards of excellence.

The following analyses of the Facility or Proposed Facility would be made during the review process:

—*Intrinsic merit of the intellectual focus and research.* What is the scientific merit of the work being conducted? This criterion concerns the Facility's overall quality of research and the likelihood that the research would lead to fundamental advances within the field, new discoveries, and/or technological developments and commercialization. The presence of unique opportunities for technical innovation would be explored.

—*Research performance competence.* This criterion relates to the capability of the investigator(s) and the adequacy of the resources that are committed to the Facility. An important issue here is the adequacy of existing or planned facilities.

—*Utility or transferability of the research.* This criterion is used to assess the likelihood that the research can contribute to the achievement of a goal that is extrinsic or in addition to that of the research field itself and thereby serve as the basis for new or improved technology, or assist in the solution of agricultural problems.

—*Appropriateness of the Research Facility approach.* Included in this criterion are the questions: Is the Facility's approach and structure essential to or appropriate to the research activities described? Would a Facility's approach add significantly to what could be done through other modes of research support?

—*Appropriateness of institutional and management plans and arrangements.* This criterion relates to the likely effectiveness of management and the strength and form of commitments to the Facility. Important additional issues include: the reasonableness and appropriateness of the budget; the mechanisms proposed or in place to enable evaluation of the Facility's progress; and the nature and level of commitment from other participants and/or sectors.

—*Effect of the Facility on the infrastructure of agriculture.* This criterion relates to the potential of the Facility and the research being conducted there to contribute to better understanding or improvement of the quality, distribution, or effectiveness of the Nation's (agricultural) scientific research and educational capabilities. An important issue here is the way the Facility relates to other institutions and facilities on similar topical issues in the Nation, Region, and State.

—*Appropriateness, and strength of linkages and knowledge transfer efforts to other sectors and groups.* This criterion is used to assess where the Facility involves or has concrete plans to involve appropriate sectors and groups in the work of the Facility, and the form and strength of that involvement. Included here are questions about the appropriateness, form, and likely success of knowledge or technology transfer efforts.

—*Performance against Strategic Plan and goals.* This section would fully evaluate the performance of the Facility in meeting its goals as set forth in its Strategic Plan.

—*The proximate, long-term economic development impact of the Facility.* Among the criteria that should be considered are the contribution to the body of basic research, development of new technologies, development of new processes, number of patents/copyrights issued, composition of industry clientele, etc.

Conclusion

The National Agricultural Research and Extension Users Advisory Board believes that a formal, professional, systemized approach needs to be applied to proposed or current funding of Federal and University agricultural research facilities. UAB further believes that the establishment of a National External Peer Review Panel and Teams, as discussed in this paper, will assure that research fa-

cility funds are providing quality performance and productivity coordinated with a long-term agricultural research policy. Implementation of the procedure could be realized within a 12-month period. The criteria for use in such an effort has been presented in this document.

It is the UAB's opinion that Congress should consider a delay in authorization and appropriation of funds for additional agriculture research facilities until the evaluations herein recommended have been submitted and reviewed for all existing or proposed facilities. Two exemptions are recommended, however. The UAB places germplasm preservation among our highest agricultural priorities and believes the importance of the National Seed Storage Laboratory in Fort Collins, Colorado cannot be overstated. Another high priority would be the Southeast Poultry Disease Laboratory in Athens, Georgia. UAB understands that these two ARS facilities have been scrutinized by a procedure similar to the one described in this paper.

Further, the UAB declares its readiness to work closely with the Congress, the Secretary of Agriculture, and the Agriculture Research community to implement these plans.

HIGHER EDUCATION NEEDS IN AGRICULTURE

(By Roger Mitchell, Dean and Director, College of Agriculture, Agricultural Experiment Station, University of Missouri-Columbia)

The strength of our competitiveness in a global agriculture will be grounded in the fullest possible development of human capital.

President George Bush, upon the occasion March 3, 1989, of honoring high school finalists in the Annual Westinghouse Science Talent Search, said:

> Scientific knowledge must be renewed and expanded in each generation. . . . There have to be the people who have the knowledge and the commitment. . . . We are not producing enough scientists and mathematicians and engineers. . . . Our national qualities of intellectual curiosity and innovation, our frontier spirit, and our habit of problem solving all uniquely equip America for the great technological age that is dawning.

President Bush properly emphasizes the key role of human capital and inspires us all to focus on that as a primary dimension of our future competitiveness as a nation and, in this particular case, in a global agriculture.

A recent American College Testing (ACT) (1989) report commissioned by the Farm Foundation emphasizes that Agriculture's future competitiveness hinges on attracting bright and capable leaders from among our Nation's youths. To achieve this, the opportunities and challenges of careers in agriculture must be brought to their attention. The ACT report offers extensive suggestions on means to inform prospective students of the opportunities.

The structural reform needed to meet the challenge in the food and agricultural sciences is a combination of factors, but the most important is to attract well qualified persons—first to educational experiences related to the food and agricultural sciences and then to provide renewal experiences to those involved in science and education for career long productivity.

Countries that possess and use scientific skills and business will lower trade and policy related costs associated with being competitive in world markets. For this reason, the number and quality of the agricultural and food sciences graduates will be a primary concern for the United States.

This need has been and continues to be very effectively met in the 1862 and 1890 "land-grant Colleges of Agriculture" called for in Morrill Acts I and II. These institutions continue to adapt to changing human capital needs of the food and agriculture sector of our society and of the world. That human capital development effort is invigorated by faculty on joint research and extension appointments with resident instruction in our "land-grant colleges" who generate new knowledge through research in the Agricultural Experiment Stations and disseminate it in the classroom through specially designed curricula, and across each State through a superb

Cooperative Extension System, as well as globally in international agriculture programs.

Recent successes underline that we know how to attract the highly qualified participants. Government, Federal and State, in partnership with Agribusiness, can extend these lessons to a wider group and ensure our competitiveness with highly qualified professionals.

UNDERGRADUATES

The Situation: A 1986 USDA report, "Employment Opportunities for College Graduates in the Food and Agricultural Sciences," projected a 17 percent average annual shortfall of qualified food and agricultural scientists and a 16 percent shortage of agribusiness, marketing and financial specialists through 1990. Such has proven to be the case to date.

During the past decade, undergraduate student enrollment in U.S. colleges of agriculture and natural resources has declined by more than one-third.

Among the many initiatives to attract students into food and agricultural areas of study, U.S. colleges of agriculture and natural resources have increased student scholarship support substantially since 1980. However, these efforts have not been sufficient to turn the supply of B.S. graduates to a positive balance.

The Experiment: In 1988 and 1989, RJR Nabisco provided funds for a total of 42 high school students to receive scholarships, two-thirds funded by RJR Nabisco and one-third by the host institution (up to $6,000 per year for 4 years made these premier scholarships for undergraduates). The students had SAT scores with an average of 1,360, 456 higher than the national averages.

The Opportunity Institutional Challenge Grants: There were 2,740 students who inquired about these scholarships in 1989. From that group, 1,009 applied and over 600 were considered qualified by the 1,200 SAT/28 ACT standard for the scholarship. This would suggest by a single, national project we have been able to attract a large number of highly qualified students.

The Federal Government should sponsor as many as 500 students per year for undergraduate study in Food and Agricultural Sciences. Because such an effort could best be handled with flexibility as well as competitiveness to fit differing needs, undergraduate student fellowships should be included as a part of a $20 million Comprehensive Institutional Challenge Grant package. Five categories of challenge grants should be developed:

1. Undergraduate Student Recruitment and Support

This effort could benefit by the excellent experience noted above with RJR Nabisco Scholarships. Such a group could be an excellent source of graduate students. At the same time, such B.S. candidates could play a key role as we complete transition from a production-oriented agriculture to a highly competitive, customer-driven, global agribusiness marketplace. The need for more competent agribusiness graduates is growing (National Agribusiness Education Commission).

2. Faculty Development

Opportunities for institutions to provide renewal experiences for current faculty in cutting edge teaching and related research.

3. Innovative Delivery Systems

These may include regional (multi-State) joint program offerings as well as satellite instructional delivery.

4. Undergraduate Research

This can serve to greatly enrich the students learning as well as increase their interest in graduate study.

5. Experiential Learning

This may include internships, practicums as well as study abroad.

Such challenge grants might well be matched by private industry and provide much needed support to stimulate curricula revitalization, enhance faculty performance, upgrade teaching laboratory equipment and attract and retain high quality students, including minorities.

Graduate Students

The Situation: Of the estimated 20,600 doctoral level scientists and engineers now employed in applied agriculture, 15 percent are involved primarily in teaching, 41 percent in research and development, and 21 percent as managers. An additional 21 percent work in such areas as marketing or regulatory activities. About 16,700 of these persons earned their Ph.D. degrees within applied agricultural science disciplines and of that number 75 percent (12,600) are currently in closely related positions. The balance of active agricultural scientists (40 percent or 8,200) earned Ph.D. degrees outside applied agricultural disciplines (National Research Council 1988).

In recent years, the distinction between applied and basic scientific research has become less marked. For example, scientists working within fields traditionally classified as applied are contributing to the development of biotechnology research methods and applied scientists often pioneer new research methods and contribute to basic scientific knowledge. Collaboration between basic and applied scientists in multidisciplinary research teams decreases the distinction between basic and applied science.

Currently available Ph.D. labor market projections are inadequate in assessing possible future imbalances in the supply and demand for agricultural doctoral scientists and engineers. Therefore, it is important that much more accurate projections be developed in the future.

The key will be to attract those non-agriculturally trained "crossover" students with the best possible skills and to especially use those skills in multidisciplinary teams. In addition, the overall quality of doctoral scientists must be continuously improved through development leaves and continuing education. In the past, the verbal and quantitative scores of students indicating a plan to enroll as a graduate student in agricultural sciences has been low compared to other disciplines. This, however, was reversed for the

pool of individuals pursuing graduate degrees under the USDA National Needs Fellowships and this program demonstrates how persons with strong academic credentials can be readily attracted by a uniquely funded effort.

The Experiment: A young USDA National Needs Fellowship Program has been exceptionally successful in the past few years in attracting about 420 doctoral and masters students of exceptionally high quality. Doctoral fellows in this program have scored some 300 points higher on the GRE than have doctoral students in other university disciplines.

The Opportunity, Competitive Graduate Training Grants and Post Doctoral Grants: Funding this program effort at $10 million annually for 10 years would support 150 new doctoral and 100 new master's students each year in targeted shortage areas. It is critical to achieve such a level if we are to be assured a baseline of high quality new scientists are being prepared.

This effort could appropriately be expanded to include post doctorals and provide opportunity for applied agricultural scientists or those from that past 40 percent pool of the non-applied agricultural scientists who have been attracted to agricultural science careers to gain a post doctoral experience and move into the pool of needed personnel under the best possible circumstances. Such post doctorals, funded at a level of $35,000 each annually, could be matched by having research costs covered by the host institution.

Special Case—International Students: A significant number of U.S. doctoral candidates are foreign students. In 1985, foreign students with temporary visas accounted for 392 of the 1,192 new Ph.D.'s in applied agriculture and 391 of 3,093 new Ph.D.'s in agriculture-related basic sciences (National Research Council 1988).

The task of training scientists from other countries, especially developing countries will continue to require special commitments by U.S. colleges and universities.

The presence of foreign students can benefit domestic student programs and institutions. They can help U.S. scientists gain a better understanding of conditions and scientific challenges outside the United States. It is likely these students will be funded by their home countries or by USAID funding or World Bank funding. But it is appropriate that we plan for their participation in our graduate education and follow up with them in the years ahead as they become a very helpful network in the world food and agricultural environmental scene.

Faculty/Agricultural Scientists

The Situation: In the last decade of the 20th century, U.S. agriculture will undergo significant changes because of factors such as biotechnology, the information revolution (e.g., computers), expanded international production and marketing and shifting economic forces. Agricultural university teaching, research and extension faculty must stay abreast of these changes and anticipate further changes.

The Opportunity Faculty Development Initiatives: Given the importance of faculty development and renewal to the vitality of col-

leges of agriculture during the coming years, we need the following:

- The national computerized Food and Agricultural Sciences Education Information System (FAEIS) needs to be expanded to provide more comprehensive data on national faculty development needs. This system resides in the USDA Office of Higher Education.
- A clearinghouse of resources for faculty development—including financial alternatives, faculty development organizations and consultants.
- A program of faculty development strengthening grants. This effort should be incorporated in the Challenge Grants above.
- Graduate emphasis on development of teaching competence.
- A graduate fellowship program for teaching—to build a cadre of faculty with particular strength for teaching to complement the present strong faculty development attention for research (the Danforth Graduate Fellowships in the 1950's and 1960's attracted an outstanding cadre of well-qualified persons to college teaching; such a focus specifically in the food and agricultural sciences by either private industry or State and Federal Government could be very appropriate at this time in our history).

There are an increasing number of persons working in industry who move into marketing, management and regulatory activities; midcareer opportunities to learn further in this area will be very important.

Additional Policy Recommendations

1. A statement to allow support of undergraduate students (current terminology is interpreted to only allow graduate students support).
2. Authorization to acquire data and maintain a national information system to evaluate and improve the quality of teaching programs.
3. Authorization to allow USDA to target institutions and populations for programs to support increasing the ethic and racial diversity of food and agricultural scientists and professionals.
4. Authorization to allow USDA to recognize and honor excellence in teaching, as it is now authorized to do in the other two primary land-grant functions, research and extension.
5. Authorization to allow USDA to address special initiatives for continuing education for practicing professionals.

Conclusion

"America's food and agricultural system is one of its greatest success stories. Everyone uses the products of the U.S. science-based food and agricultural industry. The need for more cost-efficient production and the demand for agricultural products will grow in the future as societal requirements for food and fiber increase and as production resources diminish. But these needs cannot be met without highly qualified scientists and professionals who are working to advance the frontiers of knowledge and technology. One of the most crucial variables in the food equation of the future is scientific and professional human" (Joint Council 1988).

These needs can be effectively addressed by the initiatives outlined in this statement.

References

1. American College Testing Program (April 1989), High School Student Perceptions of Agriculture College Majors and Careers.

2. Joint Council on Food and Agricultural Sciences (1988): 1988 Accomplishments for Research, Extension and Higher Education.

3. National Agribusiness Education Commission (June 1988), Agribusiness in Transition—Strategies for Change: Lincoln Institute of Land Policy, Cambridge, Massachusetts, pp. 5–6.

4. National Research Council (April 1989), "Bush: Students Should Pursue Science and Technology," p. 17.

5. National Research Council Board on Agriculture (1988). Educating the Next Generation of Agricultural Scientists—Committee on Evaluation of Trends in Agricultural Research at the Doctoral and Postdoctoral level.

6. "Operation Change: Developing Human Capital to Secure American Agriculture," Human Capital Shortages Task Force (1988), T.E. Hartung, University of Nebraska-Lincoln (chair).

7. USDA: Office of Higher Education (July 1986), "Employment Opportunities for College Graduates in the Food and Agricultural Sciences: Agriculture, Natural Resources and Veterinary Medicine. K. Jane Coulter, Marge Stanton and Allan D. Goecker.

AN AGENDA FOR THE 1890 COLLEGES AND UNIVERSITIES

(By Ocleris Simpson, Dean for Research and Extension, Langston University, Oklahoma)

The previous two farm bills played a significant role in bringing the 1890 Colleges and Tuskegee from behind and most of the institutions are now making significant contributions to economic and human resource development in rural America, as well as fostering cooperation in the economic development of the international community.

The agenda for the 1890 Colleges and Tuskegee is focused on four divergent tracts: Teaching, Research, Extension, and International Programs. The 1990 farm bill should make the continued advancement of these historically black institutions a top priority. The applied nature of most of the research works among the 1890's often make it difficult to put forth a sharp distinction between programs of research and extension. The 1890 community generally believe that this statutory entrapment may be good in that it serves to call out the need for the agriculture system to seriously review its policy of discrete program separation.

RESEARCH, EXTENSION, AND TEACHING

The Facilities Program of the 1890 Colleges should be renewed for an additional 5 years—but at a level which is lower than that which was previously sustained for either research or extension. Accordingly, PL 98-97, section 1433 as amended, should be revised to reflect an appropriated amount of $40 million for research and $10 million for the creation and operation of "Centers of Excellence" for each of the next 5 fiscal years. Such sums are to remain available until expended. The $40 million should be awarded on a competitive basis among the 1890 Colleges and Tuskegee.

Four 1890 Centers should be established:

1. National Center for Goat Research and Training;
2. Regional Center for Agricultural Engineering Development and Training;
3. Regional Center for Forest and Wildlife Biology; and
4. Regional Center for Youth at Risk.

1. *National Center for Goat Research and Training.*—One of the most quiet revolutions in American agriculture today is the rapid development of the goat industry. At the same time, one of the greatest voids in the knowledge of science is the science pertaining to goat diseases and biological efficiency, and how goats may contribute to the development of low-input sustainable agriculture. Thus, the proposed 1890 National Center for Goat Research and Training should be established.

Goat products provide many essential nutrients in the human diet and are a major source of farm income. Substantial improvements can be achieved in animal production efficiency by effectively manipulating digestive tract microflora and various physiological processes to optimize feed and forage utilization. Animal product quality can be improved by controlling cellular mechanisms responsible for tissue synthesis, and genetic engineering to improve animal efficiency. Biotechnology has enabled industry to develop products to enhance animal performance at reduced costs, but additional studies are needed to ascertain long term effects. The possibility of genomic insertions offers opportunities for improving nutrient utilization and the efficiency of tissue synthesis. Research must address factors adversely affecting estrus, ovulation, fertilization and perinatal survival of the young to improve reproductive efficiency. Studies are needed to elucidate the physiologic mechanisms controlling the synthesis of protein and fat to improve product quality.

2. *Regional Center for Agricultural Engineering Development and Training.*—The forest products industry contributes about $62 billion to the U.S. economy each year; this represents 7.5 percent of the total value of all manufacturing. In addition, tourism and recreation generates more than $200 billion; a significant portion of this amount is forest-based tourism and recreation. Recently, an increased involvement by agricultural, forestry, and related industries has taken place in international markets. Thus, American food and forest production and processing will need to become more competitive by increasing units of output—and to do this at lower costs and increased quality while making wise use of natural resources. A regional center for agricultural engineering at an 1890 College that is appropriately focused can materially help fill this gap in competition.

In order to meet world competition, numerous American industries that serve agriculture and forestry have taken their manufacturing off-shore and now import finished goods into the United States. American manufacturers of tractors went from being exporters to being importers; by early 1987 all tractors of under 100 horsepower used for agricultural purposes were produced off-shore. Much of the engineering in the production of this equipment is now done by foreign nationals—a trend which the Regional Center for Agricultural Engineering Development and Training would reverse. Approximately 90 percent of all agricultural tractors currently sold in the United States are being built off-shore, with 30 percent manufactured in Japan. Additionally, agricultural equipment dealerships have decreased from about 11,400 in 1979 to 9,300 in 1985. By 1990, dealerships are expected to number about 5,000. It is of interest to note that the top 400 family-managed farming enterprises, identified in the January 1987 issue of Successful Farming Magazine, showed that the success of these enterprises was based on their adoption of new technologies, vertical integration of production, marketing, and diversification. These enterprises have turned to highly competitive business strategies in order to make a reasonable return on their investments. Similar arrangements have taken place in the forest industry. New technologies and services—biotechnology and high technology hold

promise for keeping American agriculture, food and forest industries competitive in world marketplaces. A focused engineering research and training center can accelerate the process of moving new technologies into commercial practice.

Historically, research and education have responded to the call to help make American agriculture, food and forest industries the envy of the world. Engineers have been instrumental in improving the overall quality of life for people and they will continue to be influential in bringing about positive change. To keep America strong and its agriculture, food and forestry industries competitive in the world marketplace, new technologies, marketing and manufacturing practices, educational and technical assistance programs will need to be developed and implemented. In addition, agriculture and forestry will need to be compatible within their environments while utilizing limited resources. This will result in the need for engineers with a type of training which, in many cases today, are non-existent. The 1890 Colleges can, with appropriate resources, help fill this void. Because the need for additional expertise cuts across national, State and local levels, a regional center in proximity to a large pool of space scientists would be beneficial to the Nations future in agriculture. The Center should be focused to enhance and develop the following three areas:

Water Quality and Management

Ground water sources currently provide the drinking water of over half the population in the continental United States with 95 percent of the rural population using ground water for drinking. Agriculture utilizes 68 percent of all ground water withdrawn. Providing a long term water supply of acceptable quality in the presence of sustained agricultural, industrial, and municipal activities continues to be a major challenge in the United States. Understanding the environmental fate of chemical (persistence, mobility, transformation, and degradation in the soil and water systems) requires current emphasis so that we do not inadvertently degrade the quality of our water sources. Management techniques to reduce erosion and sediment delivery, and other pollutants, and economically maximize the efficiency of water use, particularly in irrigation, need to be analyzed, improved, and the knowledge must be disseminated. Maintaining the integrity of ground water and surface water supplies requires renewed emphasis and added engineering expertise to sustain a mission of providing adequate quantity and acceptable quality of water while sustaining agricultural, industrial and municipal activities.

Robotics in Agriculture

The control of agricultural production and processing is usually done by human operators or by simple automatic control systems which measure a single variable such as temperature, humidity, or time. In many cases, the operator assumes that process variables are constant over a period of time, although they actually change frequently. Sensors are not currently available for effectively measuring important variables such as soil moisture, plant growth, health of animals, animal performance, moisture content of flowing

grain, and rheological properties of food products. Adequate control and management of a production or processing unit depends on sensing all pertinent variables simultaneously and using the results to make an appropriate decision. Modern sensory systems include sensors and decisionmaking algorithms in online computers, and serve either as automatic controls for activating appropriate devices or as tactical management aids. More effective sensors are important for realizing the potential benefits of computers in agriculture. Improved electronic systems can help operators take more precise actions, resulting in greater output, more efficient use of energy and material resources, a safer workplace for human operators and increased economic competitiveness. Consequently, there must be a sustained mission to integrate electronic sensors, computer hardware and software, and mechanical equipment into electronic control systems that aid in the management and control of agricultural production and processing operations.

Processing and Quality Enhancement

On average, more than 60 cents of every retail food dollar pays for post-harvest activity, which includes processing, transportation, storage, preservation, packaging, and marketing. Consumers are demanding improvements in the safety, wholesomeness, and nutritional makeup of their foodstuffs. In addition, growing environmental concerns are forcing additional expenses to be incurred in handling, recycling, and disposing of agricultural wastes and residues. Emerging technologies offer opportunities to substantially improve the quality and reduce the cost of food products by improving post-harvest activities. Accordingly, the 1890 College Center should sustain a mission to incorporate recent advances in biotechnology, electronic sensors and robotic controls to improve food processing systems and ensure safe and nutritious food products. This will entail an understanding of the physical, chemical, and biological properties and structures of foods and related products, as well as the mechanisms that control biological activity.

3. *Regional Center for the Forest and Wildlife Biology.*—The proposed Center of excellence in forest and wildlife biology would focus on the following three topics:

Atmospheric Deposition on Forests, Livestock, Wildlife, and Associated Ecosystems

Many human activities are changing the chemistry of the atmosphere. The beneficial and/or harmful effects of these changes are major scientific and policy issues in many parts of the United States. The National Acid Precipitation Program (NAPAP) funds an $85 million research program each year which focuses on measuring regional emissions and deposition of airborne chemicals, and their effects on forests and water. There is little research on agricultural crops. Increased research is needed to determine if, when, where, and to what extent airborne chemicals are changing the productivity and quality of forests, crops, livestock, wildlife, and surface waters. The results can provide a basis for developing alternative management strategies, and can guide public policy debates.

Forest Productivity, Utilization, and Marketing

Global demand for lumber, plywood, particleboard, and paper is expected to expand 60 percent by the year 2000. Similar projections have been made with regard to alternate uses of U.S. Forests such as tourism and recreation. The keys to future expansion will be maintaining the health and vitality of forest resources, developing new products and processing techniques, and cultivating world markets. Consumer costs need to be kept low and export opportunities met without jeopardizing other important values of the forests.

Market Penetration and Efficient Marketing of Agricultural and Forest Products

Agricultural and forestry products have value only when provided in a form, time, and place that satisfies consumer demand. One major problem is the limited number of marketing outlets available to U.S. agriculture and forestry, even though both domestic and foreign consumers are increasingly able and willing to purchase more agricultural and forestry products. In order to satisfy both producer and consumer needs simultaneously, new knowledge is required regarding changing technologies, consumer tastes and preferences, and the scope of markets for food, fiber, and forest products. Such new information will guide future products. Also, improving the efficiency of processing and distribution operations will lower the costs of these products both at home and abroad and improve U.S. agriculture's market share in world trade.

4. *Regional Center for Youth at Risk.*—The well-being of the family, the most fundamental institution in society, is essential to national strength and economic stability. American families are experiencing rapid and, in some cases, severe economic and societal change. Difficult financial conditions in the agricultural economy are causing hardship in many rural areas. Today, 14 million children live in single-parent homes and the elderly sector of the population is increasing. New opportunities are resulting in more employment of women outside the home. These changing conditions have contributed to serious family problems. These include family disruption and dislocation, financial instability, escalating health care costs, inadequate parental care and guidance, responsibility for dependent elderly, divorce, juvenile delinquency, teenage pregnancy, drug and alcohol abuse and growing legal complexity. In cooperation with other public and private agencies, research and information programs should be provided to help families deal with these problems.

The foremost emphasis of this Center should be on prevention—intervention methods for drug and alcohol abusers and youth who are most likely to be exposed to such an environmental stress. Foreclosed FmHA farms could become major laboratory sites for working and intervening with high risk youth.

POLICY RECOMMENDATIONS

When one considers the small, but unique nature and history of the 1890 community, it is readily seen that there is a need for creating Centers of Excellence as a Centennial Moment in the new farm bill. Consequently, the Congress must consider legislation which achieves the following objectives:

(1) Establish a balanced, integrated approach to scientific teaching and educational development;

(2) Create centers of excellence;

(3) Encouraging the review of the historical policy of requiring distinct and separate programs of teaching, research, extension, and international programs;

(4) Completing the modernization of research facilities at those 1890 institutions which failed to adequately state their needs in the farm bill of 1981 by amending section 1417 of the 1985 farm bill;

(5) Extending the authorization for 1890 Extension facilities so that the full 5 years of appropriation are realized; and

(6) Raise the 15 percent floor in PL 95–113, section 1445 as amended, to a new level of not less than 20 percent, beginning with the fiscal year ending September 30, 1993.

FEDERAL SUPPORT OF ADAPTIVE AGRICULTURAL RESEARCH AND EXTENSION

(By Donald Holt, Director of the Agricultural Experiment Station, Unversity of Illinois)

> "U.S. companies forgot that innovation means small but steady improvements—not just big breakthroughs." Innovation in America, Business Week Special Issue, June, 1989.

One of the most important issues to be addressed in deliberations on the 1990 farm bill is the future direction of publicly supported agricultural science and education. This paper focuses on one constituency, farmers, and two activities, adaptive research and extension. Historically, these have been major clients and responsibilities of land-grant institutions, 1890's institutions, and the United States Department of Agriculture (USDA).

Adaptive research and the related extension programs help farmers select, implement, and manage agricultural production and marketing systems. By providing these services, universities and USDA serve as the research and development (R&D) arm of production agriculture. The results are manifested as a steady stream of small, incremental improvements in productivity and quality.

The Agricultural Research and Educational System

Components of the system: The principal public components of the agricultural research and education system are the United States Department of Agriculture-Agricultural Research Service (USDA–ARS), USDA-Cooperative States Research Service (USDA–CSRS), USDA-Extension Service (USDA–ES), USDA-Economic Research Service (USDA–ERS), land-grant institutions (including resident instruction, State agricultural experiment stations, and State cooperative extension services), and 1890's institutions.

Function of the system: Agricultural research and education, as they serve those who produce and market farm products, can be visualized as a four-step process of transforming ideas into applications (Fig. 1). The steps include:

(1) Basic research, by which we come to understand the physical, chemical, biological, economic, and sociological function of agricultural systems; and

(2) Developmental research, which produces specific new agricultural input and output products and practices.

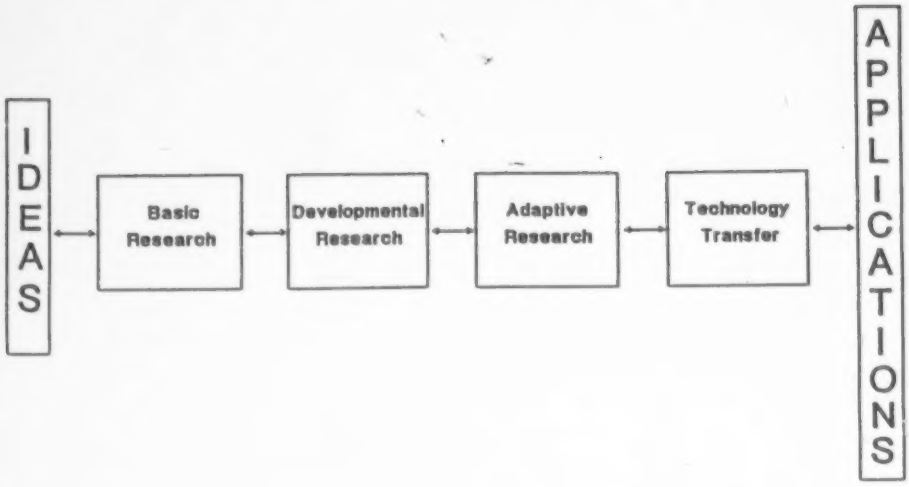


Figure 1. Conceptual model of the U.S. agricultural research and development system, depicting a linear, stepwise process of translating ideas into agricultural applications.

Other very important steps are:

(3) Adaptive research, through which information is generated that enables farmers to select from among alternative input practices and products those that are best suited to the specific soil environmental, and socioeconomic situations of the Nation's many agricultural regions and locales, and integrate these into manageable, effective, efficient, and profitable operational systems; and

(4) Technology transfer, through which the new information is transferred to users.

These categories are in no way meant to connote differences in quality, importance, or need for sophisticated techniques. They should not be prioritized, anymore than one would prioritize links in a chain. The process is actually a continuum. I have arbitrarily superimposed the categories so as to be able to describe the system in greater detail.

Private and public research and technology transfer roles: Agriculture-related basic research is conducted primarily in public and private universities and government agencies, but also by large private firms. Most product-oriented developmental research is conducted in the private sector. Most nonproduct-oriented development research, leading to specific new and improved farm management practices, including production, marketing, and financial management, is conducted in the land-grant institutions and USDA.

Adaptive research has historically been the responsibility of the agricultural experiment stations and USDA. Technology transfer, involving formal and informal instruction, demonstration, and decision-support activities, is the responsibility of the Cooperative

Extension Service and resident instruction within land-grant institutions.

Private firms, particularly dealerships, play an important role in transferring technology to farmers. They cannot accomplish the entire task, however, because they cannot provide objective, comparative information about competing products, nor do they provide much information that is not related to products.

Private consultants and professional farm managers help transfer technology to farmers and charge farmers for this service. They must draw heavily on public sector adaptive research for the information they provide. Recently, there has been increased interest in on-farm research, i.e., research conducted by farmers on their own farms.

Of course, farmers learn much by practical experience and by conducting their own comparisons. On-farm comparisons can help meet the great need for information that is both practical and site- and situation-specific. On-farm research will not replace research farm research, however, primarily because farmers are not equipped nor trained nor do they have time to:

(1) Design, conduct, and interpret complex, multifactor experiments;

(2) Measure the many things, including off-site effects, that need to be measured besides yield;

(3) Integrate the resulting information with that produced by other farmers and researchers

(4) Relate the information to macro-scale issues; and

(5) Disseminate the information to others who might benefit from it.

There will be little general benefit from on-farm research without significant involvement of the land-grant universities and USDA.

Historical development of the system: The Department of Agriculture Organic (1962), Morrill (1862), Hatch (1887), Evans-Allen (1890), and Smith-Lever (1914) acts, among others, created the public components of the agricultural research and educational system. The U.S. system was unique in placing basic, developmental, and adaptive research and technology transfer responsibilities within the same institutions, namely the land-grant institutions, and fostering close linkages between these, USDA, and the private sector.

It is important to note that the landmark agricultural legislation was not focused on individual agricultural problems or issues. The acts created institutional structure. They put in place and helped maintain an infrastructure of trained people, buildings, facilities, equipment, support services, and communication networks.

Over the years, the initial investment of Federal funds leveraged much State and private support, so that now the public institutions of agriculture are much larger and more effective than they would be if they depended only on Federal support. The Federal support, however, plays important and unique roles in the system.

By training agriculturists and fostering the development and use of productivity-enhancing, cost-cutting, quality-improving agricultural technology, this unique research and development system propelled American agriculture into world preeminence and kept it there for a century. Because of the system, the United States has

had the background information and institutional capacity to address agricultural problems when and where they arise.

Trends in Agricultural Research and Education

Emphasis on basic research: There is increasing emphasis on basic research in land-grant and other institutions. The trend is driven by increased Federal funding for basic research, administered primarily through federally administered, competitive grants programs.

Increase in private sector support for university research: Private firms have discovered that it is economical to support basic and early-stage developmental research and some product evaluation in universities. Universities compete vigorously for this support.

Shift toward basic scientists: In order to compete effectively for support, institutions concentrate their recurring resources in specific research areas in which their programs are strong and for which there are substantial amounts of outside support available. Partially in response to this trend, the proportion of agricultural scientists who are trained for and engaged in basic research has increased. Often, outstanding students are encouraged to pursue basic research careers and to avoid careers in adaptive research and extension.

Decrease in support for adaptive research and extension: At the same time that the Federal Government has increased support for basic research and the private sector has increased support for basic and developmental research, the Federal Government has reduced its support for adaptive research and extension, primarily through cuts in formula funds. As a result, the proportion of scientists trained for and engaged in adaptive research and extension has decreased.

Shift in priority setting: Most land-grant institutions now have almost all of their regularly recurring State funds allocated to the salaries of relatively permanent people. Operational support, including graduate and postdoctoral students, part-time labor, equipment, supplies, and other expenses, comes primarily from outside the institutions in the form of gifts, grants, and contracts. Thus almost all program priorities are set outside the institutions, often outside the States in which the institutions are located.

Trend toward disciplinary organization: Most agricultural units within land-grant institutions were traditionally organized along commodity lines, placing basic, developmental, and adaptive researchers and technology transfer people in the same groups. With increased emphasis on basic research and more support coming from federally administered competitive grants programs, both programs and organization have shifted toward a disciplinary focus. Some Colleges of Agriculture are reorganizing along disciplinary lines.

Change in the way formula funds are used: Since the formula research funds (e.g., Hatch, McIntire-Stennis) are not earmarked for basic, developmental, or adaptive research, administrators have shifted the use of those funds toward basic research. Administrators use formula funds to help recruit outstanding basic scientists,

support exploratory research, and bridge gaps between grants, among other strategies to help their scientists compete for grants.

Movement of institutional resources to basic research: There is tremendous pressure to move regularly-recurring university resources (mostly State funds) toward basic research. The pressure comes from university administrators and scientists who must perform and survive in largely basic research environments. Since few gifts, grants, and contracts are available for adaptive research and related extension activities, there is little incentive to invest institutional resources in that activity.

Trend toward problems and issues orientation: Increasingly, Federal support available to agriculture-related institutions and agencies is earmarked to address specific problems and issues, e.g., water quality and sustainable agriculture. Even when the programs are directed to practical agricultural problems, including sustainability, profitability, water quality, and soil conservation, there is a strong tendency to structure the resulting research and education programs as federally administered, competitive grants programs and to use a basic research approach.

Trend toward short-term funding: Most gifts, grants, and contracts are awarded for relatively short time periods, say 2 to 5 years. With the decrease in formula funds, less long-term support is available. As a result, research is conducted as projects rather than programs. Since most adaptive research and extension efforts require continuity over long periods, they are less likely to be adequately supported in the current funding environment.

Trend toward competitive grants as the funding mechanism: The basic science community, National Academy of Science, and the Office of Management and Budget, among other scientifically influential groups, strongly emphasize the need to allocate Federal research money on the basis of peer-reviewed proposals, funded through competitive grants. Centrally managed competitive grant programs are appropriate in some situations, but they are bureaucratically inefficient, unless they are very large.

A separate, high-level administrative structure is required to administer a competitive grants program. University, college, and department level administrators are wired out of the allocation process. This negates the advantages of their knowledge, experience, judgment, and proximity to the problems and opportunities. As competition increases, a smaller percentage of scientists receive support, which means that a considerable amount of valuable scientist time is spent writing unsuccessful proposals.

Scientific peer review often focuses only on scientific criteria of excellence. Other criteria, such as potential economic importance, institutional capacity to implement findings in commerce, potential for widespread adoption, and contribution to competitive advantage of constituents, must be considered in evaluating agricultural research and extension proposals.

The issue of priorities: Competition based on peer review of both proposals and results is essential, regardless of whether programs are managed at Federal, regional, State, or county levels, but peer review is not the critical issue in this discussion. The critical issue is priority-setting, and, specifically, the level at which research and extension priorities are set.

To move in the direction of competitive grant programs in a time of tight budgets and demand for accountability, decisionmakers continually seek broad consensus among scientists and science administrators as to which are the highest priority research areas. Often, lists of agricultural priorities developed at the Federal level are inappropriate for any specific State or region, because of the differences among regions in soils, climate, and socioeconomic conditions.

Central, consensus-based priority-setting tends to channel resources to subject matter areas in which there are the largest number of scientists. It concentrates resources in relatively few programs and locations. In general, it takes a long time to seek consensus, organize, and initiate central, consensus-based programs; thus they are not responsive to immediate needs and not good mechanisms if a timely response is essential. They ordinarily do not anticipate needs.

Central, consensus-based, decisionmaking often locks the system into current research and extension paradigms, thus inhibiting the independent thinkers in the agricultural science community. Private firms have learned that consensus management of operational details has a deleterious averaging effect. The principle applies as well to publicly supported agricultural research and extension. Consensus should be sought on broad objectives, not on detailed strategies.

Guidelines for Policymaking

The following are questions that should be asked concerning each proposal for change in the publicly supported agricultural research and education system, particularly as those changes would effect adaptive agricultural research and the related extension activities. Included in the response to each question are one or more examples of how the question can be addressed as policy options are evaluated and selected.

Is the program discipline-oriented or goal-oriented?

Federally and regionally administered research programs for agriculture should be oriented toward solving agricultural problems and achieving agricultural goals. To facilitate this, the linear, stepwise process depicted in Fig. 1 should be organized and operated as a parallel process (Fig. 2). Among other benefits this will shorten the time required to develop and implement new technology.

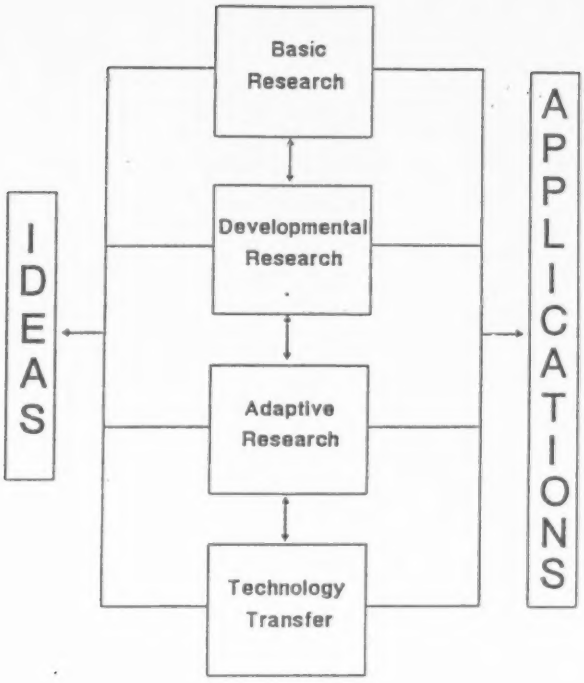


Figure 2. A parallel model of agricultural research and development, as it might be organized to speed the development of new agricultural technology.

To orient the agricultural research and educational system toward goals will require an evolutionary, not a revolutionary, change in management of land-grant institutions. Because people engaged in the essential activities—basic research, developmental research, adaptive research, and technology transfer—are usually located together in the same administrative units in land-grant institutions and because they work closely with the private sector and USDA, the parallel approach is facilitated. This has been one of the great strengths of these institutions.

Recent trends toward greater specialization, more top-down management, and funding of research through federally administered, discipline-oriented, competitive grants has tended to negate the natural advantages of the typical land-grant institutional structure and move the system toward the linear model of operation. The linear system is driven by disciplinary concerns and disciplinary decisionmaking, because basic research, the starting point in the linear model, is organized along disciplinary lines.

The parallel system, on the other hand, is driven by applications goals. Typically, an initiative launched in the parallel system would have as its objective the accomplishment of a specific market goal, conservation goal, environmental goal, etc. The investigators would be organized as a self-managed, cross-functional team or task

force with expertise in all aspects of achieving the goal. Administrators would be facilitators, marshaling resources to support the project and keeping the bureaucracy out of the way.

It often will be important to involve suppliers, producers, and consumers in the planning and execution of a goal-oriented project. There should be basic, developmental, and adaptive researchers and technology transfer people on the team. The team would identify specific needs for each of these activities during the planning process, thus making it possible to anticipate problems in implementation of new technology that can be addressed in earlier stages of research and development. Private sector experience suggests that over 90 percent of initiatives fail in the implementation stage, so consideration needs to be given to implementation very early in a strategic planning process.

It is important to emphasize that not all basic research conducted in agricultural units of institutions should be goal-oriented, nor should all basic researchers be constrained by market, environmental, or social goals. Some basic research should be conducted solely for knowledge. The National Science Foundation is an excellent administrative structure for funding and administering discipline-oriented basic research.

Example: Specific, quantitative (so you can measure progress), and achievable goals for federally supported agricultural research and extension programs might be:

To expand the U.S. share of the world commodity markets from 35 to 50 percent; or

To reduce soil losses from erosion-susceptible U.S. cropland by 25 percent; or

To increase the volume of profitable business conducted on medium-sized farms by 30 percent.

A number of such market, environmental, and social goals might be incorporated into a federally supported program. It would be a mistake to specify in the legislation the research and extension strategies by which these goals should be accomplished. These will differ among the diverse regions, States, and locales of the Nation.

Proposals for goal-oriented initiatives should specify the goal, list the existing constraints to achieving the goal, and outline the organizational approach to removing the constraints and implementing the new or improved production and marketing systems. The results should be evaluated on the degree of success in achieving specific goals rather than the number of publications or other intellectual products generated by the research and development effort. In agricultural science, peer-reviewed publications and other scholarly products are means to an end, not an end in themselves.

Can the resulting products and practices be implemented profitably?

Those who propose technological changes in order to accomplish social, political, and environmental goals must consider the critical issue of who must implement the changes. If farmers cannot implement proposed changes as part of profitable farming enterprises, the changes will not be implemented and nobody's objectives will be served.

An unprofitable operation, by definition, is unsustainable, unless one wishes to make farmers wards of the Federal Government.

Farmers and agribusiness people must survive in the short term in order to survive in the long term. If the family farm is to survive as a way of life, it must be able to survive as a business.

Example: Proposals for developmental and adaptive research and technology transfer, even if they are directed toward environmental or conservation issues, should explain how the potential new products and practices will be implemented in farming and how they will contribute to profitability and competitiveness in both the short and long term.

Does the proposed legislation address infrastructure as well as program support needs?

To accomplish any substantive research or extension goal, there must be an infrastructure in place within which to conduct a program and there must be funds to offset the unique costs of the program. When Government mandates activities and does not provide support for both infrastructure and program, the chances of success are small. States cannot be expected to provide all the infrastructure needs for demanding Federal programs. Indirect cost recovery associated with grants is not an adequate mechanism to sustain an effective infrastructure, because it doesn't meet the need for continuity.

Example: This problem can be addressed by insisting that any proposal for federally supported agricultural research and education address both infrastructure and program needs.

Does the proposed legislation provide an appropriate balance among basic. developmental, and adaptive research and technology transfer?

Agricultural R&D is a process involving all of these activities. To the extent that one is inadequately supported and/or poorly managed, the entire effort is doomed to failure. By adequately supporting each of these activities, government establishes a direct link between basic knowledge and economic development and paves the way for a good return on public investment in the system.

Example: Support for the proposed National Agricultural Research Initiative should not be focused on basic research alone, but should strengthen the entire system of agricultural research and education.

Are the objectives broad enough for decisionmaking at this level?

Just as it is very poor business practice for corporate-level decisionmakers to make operational and middle-level management decisions, it is unwise for top-level agricultural decisionmakers, namely, legislators and agency heads, to make decisions about specific research and extension approaches to problems, especially agricultural production problems, which are usually site- and situation-specific.

Example: Instead of focusing resources on low-input systems, set reasonable, quantitative goals for profitability and resource conservation. Then earmark support for adaptive research and extension on the production and marketing of farm products and provide program and infrastructure support in that broad, general area.

Is the emphasis of the proposed program on results rather than process?

When formulating policy relative to agricultural research and education, legislators should avoid mandating specific research and extension procedures and programs. Instead, specify the desired results and measure progress toward achieving those results.

Example: To address agriculture-related environmental problems, set standards and goals in terms of environmental quality, food safety, and profitability (sustainability). Allow local scientists and administrators as much freedom as possible to select appropriate approaches to achieving those standards and give them enough support to execute the programs.

Are the right things being measured?

For the same reason that Federal agricultural research and education policies should specify desired results rather than procedures, it is important for those monitoring progress on federally supported research and education efforts to measure the appropriate variables.

Example: To evaluate progress toward achieving the goal of sustainability, measure trends in profitability, soil productivity, and environmental quality. To measure progress toward competitiveness, measure profitability and market share. It is very important to heed the private sector admonition that "What gets measured gets done".

Does the reward system provide incentives to achieve the stated objectives:

At present, the reward system in publicly supported agricultural research and education provides strong incentives for excellence in basic research. There should be better ways of recognizing and rewarding efforts, particularly group efforts, in which important market, environmental, and social goals are achieved through well-conceived, well-implemented, and well-managed research and education programs. There should be rewards for scientists and extension people who develop and foster small, incremental changes of benefit to agricultural practitioners and consumers. Likewise, there should be some rewards for trying innovative approaches to achieving goals, even if they fail.

Is the management of the proposed program sufficiently decentralized?

The enormous geographic complexity of agriculture dictates that decisionmaking must be moved as close to operational realities as possible. In agriculture, as in other industries, even the most dramatic technological breakthroughs are ultimately implemented as small incremental improvements in productivity. The vital adaptive research and technology transfer activities that enable these small incremental improvements in productivity must be conducted as close to the specific production and marketing situations as possible.

Does the proposed research strategy fit the problem being addressed?

Recent legislative proposals specify strategies, including product differentiation, diversification, and vertical integration, toward which research is to be focused. Often, the strategies are not appropriate for stated objectives. To illustrate, private sector experience suggests that being the low-cost producer is the only viable strategy for most commodity producers. Vertical integration and diversification are good approaches for large conglomerates and for industries as a whole, but not for most individual operations, especially small ones. Achieving product differentiation in specific niches or in commodity markets is very difficult and is an expensive and risky strategy, from a research and development standpoint.

Example: A proposal for support for research on new products and uses should specify where, i.e., here or abroad, and at what level, i.e., inputs, production, processing, or marketing, the resulting new technology will be implemented and how that will benefit producers. Recognize that commodity producers must compete on the basis of cost of production.

Does the funding mechanism fit the problem?

The mechanism by which a publicly supported research/education project is funded should fit the goal of the proposed program and the site- and situation-specificity of problems being addressed.

Examples: If the goal of a proposed program is to obtain scientific knowledge, federally administered, discipline-oriented competitive grants are appropriate funding mechanisms. If the proposed goals are market, social, or environmental, Federal-, regional-, and State-administered, goal-oriented competitive grants may be appropriate. If the problem being addressed is very site- and situation-specific (e.g. water quality), it would be appropriate to target formula funds on the related research and education efforts. If the goal is to sustain and improve the infrastructure or to support programs rather than projects, formula funds are the best mechanism.

Conclusion

The capacity of the publicly supported agricultural research and education system to conduct adaptive research and the related extension activities is eroding. That capacity can be enhanced by sound research and education policy at the Federal level.

Adaptive agricultural research and extension benefit the early adopters of new technology and consumers. They are extremely important to achieving the national goals of agricultural competitiveness and sustainability. They are also essential to conserve natural resources; preserve and enhance the environment; provide safe, high quality, and affordable agricultural products; and preserve rural institutions, including that most hallowed institution, the family farm.

CONDUCTING AND IMPLEMENTING RESEARCH IN PRODUCTION AGRICULTURE; A UNIVERSITY BENCH SCIENTISTS' VIEW

(By Marvin K. Harris, Professor of Entomology and Philip J. Hamman, Extension Urban Entomologist and Program Leader for Entomology, Texas A&M University, College Station, Texas)

Redefining the Mission and Reaffirmation of the Clientele

The land-grant university systems including the State Agricultural Experiment Stations, the Cooperative State Extension Services and Colleges of Agriculture have fostered a unique environment for conducting, implementing, and educating our citizens about research in production agriculture. The purpose of this paper is to provide a university bench scientists' view of this process and to discuss ways to improve the conduct and implementation of research in production agriculture.

The institutional framework described above has evolved for more than 100 years—from a time when most citizens were closely associated with agriculture to the present where barely 1 percent of the U.S. population actually produces food and fiber for the Nation. This dwindling population of producers rely on agricultural research to provide ways to feed and clothe an increasing population, but, from the very beginning, the principal beneficiaries of agricultural research have been the consumers of increasingly higher quality, more abundant, low cost food and fiber available throughout the year. The gradual disassociation of consumers from direct participation in production agriculture over the past century has created a communication gap between those involved in agriculture and the rest of society. Agricultural institutions have been increasingly successful in contributing to food and fiber production, processing, marketing and storage but have become increasingly isolated from the consumer/taxpayer.

The mission of agricultural research and implementation originally emphasized increasing the quantity and improving the storage of production in an economically efficient manner. This multifaceted mission has always been primarily focused on the agricultural producer because producers were and are the originators of food and fiber for the consumer. A century ago, farmers and their families also constituted a significant portion of the consumer group, and institutions responsible for production agriculture came to be viewed as working for farmers rather than working with farmers for consumers. This was a fine distinction a century ago but is of crucial significance today because farmers and associated agribusinesses now constitute only a tiny fraction of the consuming population.

Institutions, by their nature, are slow to change. Thus, research priorities established a century ago emphasizing yield, storage and low cost production remained in place until a decade after World War II when food quality and environmental and social issues began to emerge as technology revolutionized agriculture. The agrarian mentality still permeates our society and its institutions, but the images we retain bear little resemblance to the industrialized farmers of today that produce our food and fiber. This anachronistic image has provided a continuing measure of consumer support as urbanization of the population took place. Agricultural research and implementation proceeded virtually oblivious to these social upheavals and skewed perceptions, continuing to modernize the agricultural production process by adopting new technologies as quickly as they became available. Publication of *Silent Spring* came as a shock and the price of agricultural progress has become increasingly evident to everyone over the generation that has followed. Unanticipated technological complications continue to plague production agriculture and resolving these problems requires reinvolving the consumer in the process.

The new challenge of *producing a reliable supply of more high quality food and fiber at less cost with the least adverse impact on the environment* goes beyond the farm community. There are alternatives to how we conduct production agriculture. But these too have a price, and the informed consumer/taxpayer should play a role in establishing which alternatives should be pursued at what price and what contingencies are most attractive when complications occur.

The Research Process

The typical agricultural research scientist is an expert in a particular aspect of a discipline. The scientist knows a lot about soil morphology or insect physiology or fungal epidemiology or economics of small farms, for example, and even within that small area, further specialization is typically required to develop a sufficiently complete understanding to find new ways to make decisions and take actions that impact production agriculture. The agricultural research scientist is guided by general principles derived from his/her discipline, and pursues specific investigations that offer the most promise for satisfying some general objective established by his/her employer. "Cheaper more abundant high quality food and fiber, reliably produced at less cost while minimizing adverse effects on the environment" would be a typical general objective. The university bench scientist is further guided by a job description and title that identifies an area or commodity assignment where efforts are to be concentrated, i.e., "insect toxicology" or "small grains plant pathologist".

The researcher is usually free to concentrate on particular aspects of this general objective commensurate with his/her skills and resources, but funding availability typically determines which aspect receives the most attention. This funding can be provided by Federal, State, industry or private sponsors as part of a targeted effort in a particular area or it may be resources allocated after a competitive process based on submitted proposals. Either way,

guidelines are typically established from the top and specific research objectives of the individual scientist must conform to the program to be eligible. Opportunities for individual university bench scientists to vigorously pursue promising research areas outside of existing guidelines to impact production agriculture are very limited. Resources are scarce to begin with and most of them will be earmarked for areas outside the specialty of the researcher in production agriculture.

During the past two decades in our experience, existing resources have been seriously eroded by inflation and new resources have been earmarked for long range high risk efforts to make seminal breakthroughs in the conduct of production agriculture by emphasizing novel areas of science previously unassociated with funding from agriculture. Chemical ecology and genetic engineering would be two examples of these efforts. The dramatic expansion of the research process to many new areas and the erosion of resources in established programs has resulted in exacerbating already serious deficiencies in the development and flow of information and technology from the idea stage to application in production agriculture.

Our criticism is not in the direction resources have taken but in the degree to which they have been allocated to various facets of the agricultural production process. Progress in production agriculture has historically been made in small incremental steps and the few new resources for conventional work tend to be reactions to severe problems that develop rather than the implementation of a proactive well balanced strategy for production agriculture. The front line production agriculture research scientist today has very limited resources and is confronted with new problems on a regular basis. They are backed by a cadre of scientists increasingly removed from agricultural expertise and commitment who derive their rewards from grantsmanship, refereed journal publication and research findings that promise to impact agriculture in a decade or longer in the future.

Some agricultural institutions have gone so far as to adopt the view that research should be concentrated only in areas promising seminal breakthroughs with a decade plus time frame. This may result in excellent science but threatens to destroy the linkage between a research commitment to improving production agriculture today versus tomorrow. This is problematic because the farmer and, more importantly, the human valued resources they produce, must survive today to get to tomorrow. The luxury of a decade plus research horizon can only be justified if sufficient agricultural resources are committed to improve agriculture in the short term as well. In any event, the linkage between ideas and impact on agriculture must be strengthened even more if the diverse groups currently using agricultural resources are to be successful.

Linking Agricultural Research to the Producer and Benefiting the Consumer

The State Agricultural Experiment Stations (CSRS) and the State Cooperative Extension Services (ES) provide a framework for linkage from the Idea to Consumer Benefit in the research and implementation process (Figure 1). These institutions originated from

separate Federal legislation. The Hatch Experiment Station Act of 1887 emphasized agricultural research and the Smith-Lever Act of 1914 emphasized implementation of that research. These institutions typically became embedded in colleges previously established by the Morrill Land-Grant College Act of 1862. As a result today, agricultural education, research and implementation efforts are intertwined in the bureaucracy and usually in the physical facilities of each State. The State also has the prerogative to provide joint appointments of personnel so that a single individual could be assigned to address all three missions of teaching, research and Extension. This flexibility can address the primary mission in each area given the administrative vision and commitment to support each responsibility in an equitable manner. The major challenge is to balance available resources among these areas so that information developed from research can be carried through to the implementation and educational phases in an efficient and expeditious manner.

FIGURE 1. An outline of the linkage from an idea to having an impact on agricultural production and benefitting the consumer.

General Objective: To reliably produce cheaper more abundant high quality food and fiber at less cost with minimum adverse effects on the environment.

Specific Objective: Participate in one or more phases of the research/Extension process and maintain a commitment to the general objective.

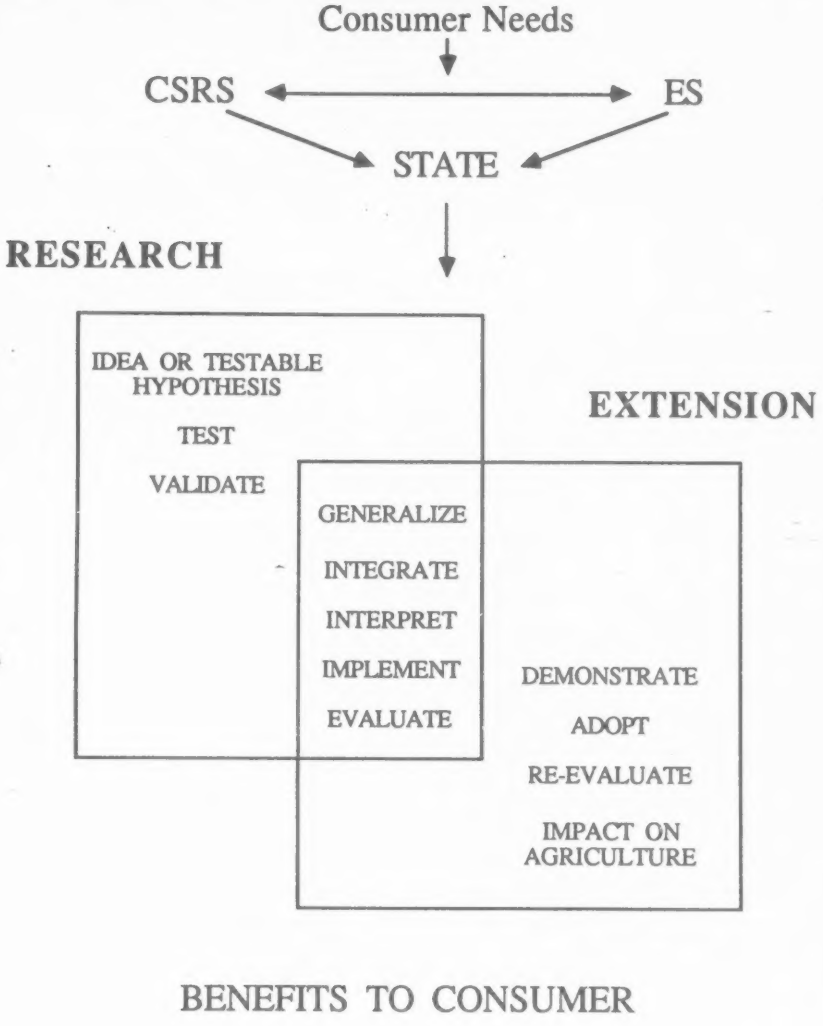


Figure 1 illustrates that linkage. A researcher begins with a testable hypothesis because that's the way science operates; this must be clearly understood by everyone if public expectations of agricultural research are to be satisfied. A testable hypothesis is an idea that can be examined. For example "insects damage crops" is a hypothesis but would require examining hundreds of crops and thousands of insects to conduct a complete test and few scientists would have the expertise let alone the resources to carry out the work; "pecan nut casebearer damages pecan" is a more manageable hypothesis representing one insect on one crop. Agricultural research on the pecan nut casebearer involves a pecan entomologist, also usually responsible for research on the dozens of other arthropod pests of pecan.

Testing the hypothesis "pecan nut casebearer damages pecan" requires experiments where the insect is given access to some pecans and kept away from others. If significantly more pecans are consistently harvested from pecans where pecan nut casebearers have been excluded, the researcher concludes the pecan nut casebearer is responsible for the yield loss. Then the general question arises "How can this yield loss be prevented?" There are many possibilities and each requires more research. The pecan entomologist forms a research plan that attempts to both provide an immediate stop-gap solution and that has a long range goal of finding the best solution possible. Stop-gap measures typically use off-the-shelf technology developed by other entomologists in the discipline and are adapted for the pecan nut casebearer by the pecan entomologist. A broad spectrum insecticide applied whenever the damaging stage of the pecan nut casebearer might be present would be an example.

The best solution can be investigated once a stop-gap measure is found. This usually involves developing a precise understanding of exactly how and when the insect causes damage and the determination of what factors reduce or enhance the likelihood of damage. The condition of the pecan, natural enemies of the casebearer and weather are important factors here in addition to the pest itself. As ideas develop, communication must be established and maintained with colleagues in entomology to ensure the work uses the latest approaches, with colleagues in other disciplines to ensure solutions under investigation are compatible with their approaches, with Extension personnel, industry, consultants and producers to ensure solutions can actually be applied, with economists to ensure solutions are economically feasible and with other agencies and consumers to ensure the product will be acceptably produced. This is a time consuming and often expensive endeavor. Many ideas fail in this process but even a small measure of success can justify massive effort.

The following example from my laboratory illustrates this point. One reason for using this example is that we believe it is typical of the kind of small scale incremental progress that is at work in agriculture. Research on the pecan nut casebearer in collaboration with the people identified above, has resulted in a method to predict when the pest can cause damage, a sampling approach to determine if the pest density warrants treatment, and identification of effective insecticides that can be used in combination with fertilizers and fungicides that are likely to be needed at the same time.

Growers using this new technology can reduce treatments from 2–4 to 1–2 treatments per season at an average savings of $20 per acre. There are over 100,000 acres of managed pecan in Texas alone and some 300,000 in the United States giving a potential direct savings to the producers of $6 million annually and 75,000 fewer gallons of insecticide used in the environment. Cheaper production costs means less expensive food and less pesticide means cleaner food and a cleaner environment as well as reducing the likelihood that resistance to the insecticide will develop and render the chemical ineffective.

Realizing the potential of this work requires getting the information to the producer by personal interaction at grower meetings and workshops and cooperation with Extension, consultants, industry and consumers. Time in this area is well spent, but this activity does reduce the time available for additional research that can result in more new and needed technology.

The Cooperative State Extension Service in particular is especially well prepared to participate in taking validated and generalized ideas and integrate them into existing programs all the way to the county level so that their full impact can be made on agriculture. Extension has a network of generalists and specialists who interface between the researchers developing information and the public. Each Extension responsibility is sufficiently broad to require interaction with numerous research programs and user groups, yet hopefully flexible enough to allow a focused impact when new technologies emerge. Extension specialist responsibilities typically are divided by discipline and have two or more commodity assignments like small grains, corn, cotton, cattle, pecan, etc.; but, generalists like county agents cover the entire spectrum of disciplines and commodities in each of their respective counties. Implementation of research information that requires a significant and continuing education component to a large number of users finds this Extension network invaluable.

CSRS and ES Interaction at the Bench Level

CSRS and ES interaction can be illustrated by referring again to Figure 1. The Idea level of agricultural research is a maelstrom of activities ranging from Star Wars-like research to low-risk, fish-in-a-barrel certainties that compete for research resources. The former tend to be long-term and high-risk ventures without current contact with an implementation process whereas the latter are likely to have a target audience and an implementation plan in mind. In both cases, the research must proceed through the validation stage before practical applications can be seriously considered. Other researchers are usually enlisted to generalize the results to the area or world at large and efforts are then turned to integrating the new technology into existing systems. This is a transitional phase between research and implementation that requires tailoring the results to the idiosyncrasies of each real world system and seldom is this an off-the-shelf operation. The specialized researchers know the breadth and depth of the new technology, including its technical limitations, but they are less likely to be familiar with the target audience who will implement this technology. Converse-

ly, Extension personnel know the latter system and, equally important, have the confidence of the target audience, but Extension personnel need to become familiar with the new technology before staking their professional reputations on programs incorporating the new work.

Funding for joint Research-Extension transitional efforts is not always easy to obtain because researchers are reluctant to devote scarce resources to "proven" technologies and Extension personnel are reluctant to adopt "experimental" technologies that may not work in the field environment the same way they performed in controlled studies. This hurdle can only be overcome when strong mechanisms that encourage interactions are in place. Successful CSRS and ES interaction to benefit the consumer occurs when good scientists share the commitment explicitly stated in Figure 1. They achieve excellence when enlightened administrators provide mechanisms to encourage that process and facilitate ways to overcome institutional barriers to getting that job done.

Opportunity for failure in cooperative CSRS/ES work is increasing for the following reasons. Academic credentials of CSRS/ES scientists are better than ever but their backgrounds are increasingly urban so that they lack a hands on understanding of production agriculture and a natural empathy with producers. This problem stems from both the urbanization of our society and from the expanding umbrella of agricultural research that encompasses new technologies not previously associated with production agriculture. These scientists need to be provided with a clear mission orientation from the highest level. The currency for professional development of research scientists is scholarly publication and that of Extension is program development and delivery. These criteria are sound but need to be combined so that professional development of scientists in production agriculture is examined and rewarded in the context of the overall mission. CSRS and ES formula funding arrives and is accounted for separately at the State level. This can impede interaction when already scarce resources need to be committed to the interface activities in Figure 1. The worst case scenario at present occurs when personnel are hired and housed separately and distinct lines are drawn between the missions. Finally, and perhaps most importantly, agricultural priorities developed at the Federal level usually reflect either CSRS or ES missions and resulting programs have significant barriers that discourage interaction by not allowing co-CSRS/ES principal investigator's on grants, establishments of guidelines that essentially demand either scholarly publication or program delivery, but not both, and not allowing funding to be shared.

Given these impediments to interaction, some attention should be given to why the existing system works as well as it does. The primary reason is the commitment of scientists to their respective disciplines as they relate to science, agriculture and society. The role of the discipline is a driving force in motivating scientists. The complementary disciplinary structure of CSRS/ES is precisely what allows scientists at the bench level to interact in an atmosphere of mutual respect and to share a common commitment to the mission embodied in Figure 1 despite the obvious institutional, funding and administrative barriers inherent in the system. Inter-

disciplinary respect and cooperation results from shared perceptions of challenges and needs between disciplines and often a commodity responsibility ties these diverse scientists together in productive albeit *ad hoc* teams. The entire system could be strengthened by supporting disciplines and encouraging interdisciplinary and interinstitutional interactions to a greater extent.

New Roles for CSRS/ES Interaction

The expanded mission of *reliably producing low-cost more abundant high quality food and fiber at less cost with minimum adverse effects on the environment* has expanded the breadth of production agriculture dramatically in recent years to embrace disciplines and create subdisciplines where none existed before. The reasons for this expansion are a recognition by agricultural institutions of the increased opportunity for new knowledge to improve agriculture and benefit consumers, and increased pressure from forces largely external to agriculture that question the quality and reliable production of our food and fiber and the quality of the environment that results from present practices. Most new resources have been directed at these opportunities and concerns looking for seminal breakthroughs in research. We need new knowledge and we need the means and the direction to implement it. The conventional CSRS/ES bench scientists are the vehicles that have and we believe will catalyze agricultural change by adapting and integrating seminal breakthroughs into the production agricultural system.

Old roles emphasize hardware like hybrid seed or animals, mechanization and application of chemical fertilizers and pesticides. These will continue to be important. New roles will emphasize software approaches where decision making aids to production agriculture will predominate. For example, insecticides originally protected human valued resources by prophylaxis. Research found new chemicals and Extension advocated their use. Today, problems of insect resistance to insecticides coupled with environmental concerns causes research to seek solutions that minimize their use and Extension to deliver these complex programs. Genetic engineering provides a look into the future with the prospect of transgenic plants that incorporate insecticidal toxins in their tissues. Optimists unfamiliar with the genetic plasticity of insects expect this to be a panacea for insect control. It is clear to the agricultural bench scientist familiar with pests and toxins that the transgenic pest resistant plant emerging from the laboratory of the molecular biologist will require an as yet unspecified management program to be effective in the field. The transgenic plant will be vulnerable to pests developing resistance to it, to take the simplest example, and the manner in which the plant is deployed will determine how quickly that vulnerability is manifested. Further research is needed to identify our options regarding how to adapt this new tool to the field and how to integrate it within the agricultural production system. This is but one example where our broadened research efforts provide new tools that need to be integrated into production agriculture.

The new roles for CSRS/ES bench scientists will be in adapting this information for use and developing programs that work to im-

prove production agriculture and benefit the consumer. The fulfillment of this mission can no longer be accomplished by just concentrating on bringing programs to the county agent/farmer interface where the technical transfer of new information occurs. The increasing sensitivity of the consumer to how we conduct production agriculture is readily seen in issues like medfly eradication in California and the use of Alar™ on apples. A new coalition is needed to mobilize the frustrations of producers and consumers into productive actions that capitalize upon the expertise, linkage and commitment to production agriculture shown in Figure 1. The CSRS/ES bench scientist has the skill and desire to improve this process. Support is needed to coordinate the efforts of scientists and to interface their abilities with nontraditional segments of society consisting of environmentalists, concerned consumers, etc. to plan, conduct, evaluate and implement research that truly meets consumers needs. The bench scientist has a crucial role to play in this process in developing the scope of research, communicating the range of possible solutions to the production agriculture and consumer community, formulating those programs that offer the greatest promise and delivering those successful programs to the consumer.

Policy Recommendations

1. An explicit recognition should be made of the expanded CSRS/ES mission of reliably producing low-cost more abundant high quality food and fiber at less cost with minimum adverse effects on the environment.
2. The consumer should be explicitly recognized as the ultimate target of CSRS/ES efforts and provisions should be made to obtain input by including consumers as well as traditional representatives in planning and programming efforts.
3. Institutional barriers to CSRS/ES cooperation should be recognized and ameliorated by encouraging joint appointments and formation of research/Extension teams that allow principal investigator interchangeability, resource sharing and a broader view of professional development.
4. New resources and programs should be developed that support the CSRS/ES interface between the completion of validated research and demonstrating that work in the producers field to a consumer audience.